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Summary and Analysis of Comments on the Recommended Practice for the Measurement of Refueling Emissions

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As a result of concerns abouth the emissions whcih occur when gasoline vapors are displaced from fuel tanks during the refueling of motor vehicles, EPA has been examining the need for the control of these refueling emissions and the methods to do so. One such method involves the collection on the vehicle of the displaced hydrocarbons and the measurement of the effectiveness of the refueling vapor control system. This type of control is referred to as onboard control of refueling emissions.

This report presents a summary of the comments on the recommended refueling test procedure, EPA's analysis of the issues raised by the commenters; and the resulting changes made to the recommended test procedures.

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I. Introduction

As a result of concerns about the emissions which occur when gasoline vapors are displaced from fuel tanks during the refueling of motor vehicles, EPA has been examining the need for the control of these refueling emissions and the methods to do so. One such method involves the collection on the vehicle of the displaced hydrocarbons and the measurement of the effectiveness of the refueling vapor control system. This type of control is referred to as onboard control of refueling emissions. On August 22, 1985, EPA transmitted to interested parties two technical reports concerned with the measurement of refueling emissions. One report, "Refueling Emissions from Uncontrolled Vehicles,"[1] detailed EPA's baseline emissions measurements of refueling emissions and the second report, "Draft Recommended Test Procedure for the Measurement of Refueling Emissions",[2] presented a test procedure for the determination of the effectiveness of onboard control of refueling emissions. These reports were accompanied by a draft recommended practice, "Subpart C - Refueling Emissions Test Procedure."[3]

Recipients of the reports and draft test procedure were requested to review and provide comments on EPA's recommended test procedure, including comments on the test parameters and the test equipment. As a result of on-going EPA analyses of the test procedure issues and the comments provided by the reviewers, EPA revised the test procedure. On April 10, 1986 EPA convened a technical meeting to present and discuss the revised refueling test procedures. In addition to the oral comments provided during the meeting, EPA requested that the participants provide written comments on the revised test procedure. Comments on both the original and revised test procedures were received from the following organizations:

- American Petroleum Institute (API)
- California Air Resources Board (CARB)
- Chrysler Corporation
- Ford Motor Company
- General Motors Corporation (GM)
- Motor Vehicle Manufacturers Association (MVMA)
- Nissan Research and Development, Inc.
- Radian Corporation
- Toyota Motor Corporation

This document presents a summary of the comments on the recommended refueling test procedure, EPA's analysis of the issues raised by the commenters, and the resulting changes made to the recommended test procedure.

The remainder of this document is subdivided into two major sections. Section II presents the summary and analysis of test procedure issues. The comments received on a particular issue are first identified and then followed by EPA's analysis and response. Section II is subdivided into six subsections. These subsections address: test parameters, fuel tank heating, facility requirements, canister loading, preconditioning, and miscellaneous issues. The final section, Section III, is an overall description of the test procedure which has been developed as a result of the comments and EPA's analysis of the comments. The Appendix following Section III describes the canister testing program carried out in support of the analyses in this document.

II. Summary and Analysis of the Comments

A. Primary Parameters Affecting Refueling Emissions

In the draft recommended procedure, five key parameters affecting refueling emissions were identified. These parameters were: dispensed fuel temperature, differential temperature between dispensed fuel temperature and fuel tank liquid temperature, fuel volatility, fuel dispensing rate, and fuel level prior to refueling. The values for these key parameters directly affect refueling emissions and were chosen with the goal of insuring emissions control for most all expected in-use conditions. To do this, the values of each parameter were chosen at approximately the 90th percentile point from distributions of in-use survey data. Test parameter values as originally proposed in the draft recommended procedure are listed in Table 1. Revisions have been made to three of the five test values for the parameters as a result of comments received and further EPA analyses. While the reasons for these changes are discussed in the remainder of this section and subsequent sub-sections, the revised values are listed here in Table 2 for ease of comparison.

1. Temperature Specifications for Dispensed Fuel and Liquid Fuel In The Vehicle Tank

In commenting on the stringency of the refueling test parameters, a number of motor vehicle manufacturers took the position that the values were overly stringent. The manufacturers stated that the selection of the 90th percentile of both the dispensed fuel temperature and the tank temperature would result in greater than the 90th percentile of refueling events being represented by the test procedure. According to these manufacturers, the test values selected in the draft test procedure would represent approximately the 99th percentile of refueling events.

This document presents a summary of the comments on the recommended refueling test procedure, EPA's analysis of the issues raised by the commenters, and the resulting changes made to the recommended test procedure.

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Table 1

Draft Recommended Procedure, Critical Test Parameters

Parameter	Meaning	Value
1. Dispensed Temperature, T_D	Temperature of dispensed fuel	88 ± 2°F
2. Temperature Differential, ΔT	Tank temperature minus dispensed fuel temperature	+2 to +5 °F
3. Volatility, RVP	Test fuel volatility expressed in Reid Vapor Pressure	11.5 ± 0.5 psi
4. Dispensing Rate	Flow rate of fuel as it is dispensed	8-10 gal/min
5. Fuel Level	Level of fuel in vehicle prior to refueling. Percent of capacity to nearest 0.1 U.S. gal	10%

Table 2

Revised Critical Test Parameters

Parameter	Meaning	Value
1. Dispensed Temperature, T_D	Temperature of dispensed fuel	81-84°F
2.Tank temperature T_T	Soak area temperature	80 ± 3°F
3.Volatility, RVP	Test fuel volatility expressed in Reid Vapor Pressure	In range of 8 to 11.5 psi (Final determination to be made on results of Volatility Study)
4. Dispensing Rate	Flow rate of fuel as it is dispensed	Refueling measurement: 9.8 ± 0.3 gal/min. Canister loading: 3-4 gal/min.
5.Fuel Level	Level of fuel in vehicle prior to refueling. Percent of capacity to nearest 0.1 U.S. gal	10%

The commenters are correct in their basic contention that the selection of the 90th percentile for the dispensed fuel temperature and fuel tank temperature will result in the combined percentile being higher the individual percentiles. EPA disagrees, however, with the assertion that the test values would represent the 99th percentile of refueling events. First of all, the parameters are not fully independent variables, making it difficult to assess the combined probability of occurrence of extreme values. Second, both parameters do not have to be at their 90th percentile values to generate high emissions. As the value of one of the parameters rises beyond that point, the other can fall correspondingly below its 90 percent value and still produce overall high emissions. Therefore, to analyze the total effect of these parameters on refueling emissions, EPA went back to the basic field survey data and constructed an estimated emission rate distribution from the fuel and tank temperature data.

The dispensed temperature and ΔT data used in this distribution were taken from a 1975 gasoline temperature survey conducted for the American Petroleum Institute (API) by the Radian Corporation, the same data that was used in the draft recommended procedure report.[4] The temperatures are from the four ozone-prone regions in the country (shown in Figure 1) for the critical months of May through September. The fuel volatility was assumed to equal the ASTM upper limit. Refueling emission rates were calculated from the survey data using the following emission factor equation developed by EPA from refueling test data from uncontrolled vehicles:[1]

$$\text{Emissions (g/gal)} = -5.909 - 0.0949(\Delta T) + 0.0884(T_D) + 0.485(\text{RVP})$$

The distribution of the estimated refueling emission rates is presented in Figure 2. Assuming the individual 90th percentile temperatures, T_D=88°F, ΔT=+2°F, and the fuel RVP=11.5, the resulting emission factor is 7.26 g/gal. As can be seen from Figure 2, this value (7.26 g/gal) represents approximately the 93rd percentile of the calculated distribution for summer refueling events.

Radian Corporation performed a similar analysis in a report submitted to EPA at the April 10 workshop.[5] Radian's analysis, which included consideration of relative refueling amounts, indicated that the specified test parameters require systems that control over 99 percent of the refueling cases during ozone-prone seasons. While not disagreeing with Radian's basic approach, EPA believes that there are other factors which must be considered in an overall stringency evaluation. Perhaps chief among these factors is the assumed driving pattern used to evaluate system purge. As will be seen later in the discussions of canister preconditioning, EPA has used a driving sequence of three trips per day as the basis for system evaluation. This pattern allows a fairly generous amount of canister purge and represents typical conditions

OZONE PRONE REGIONS DURING SUMMER MONTHS

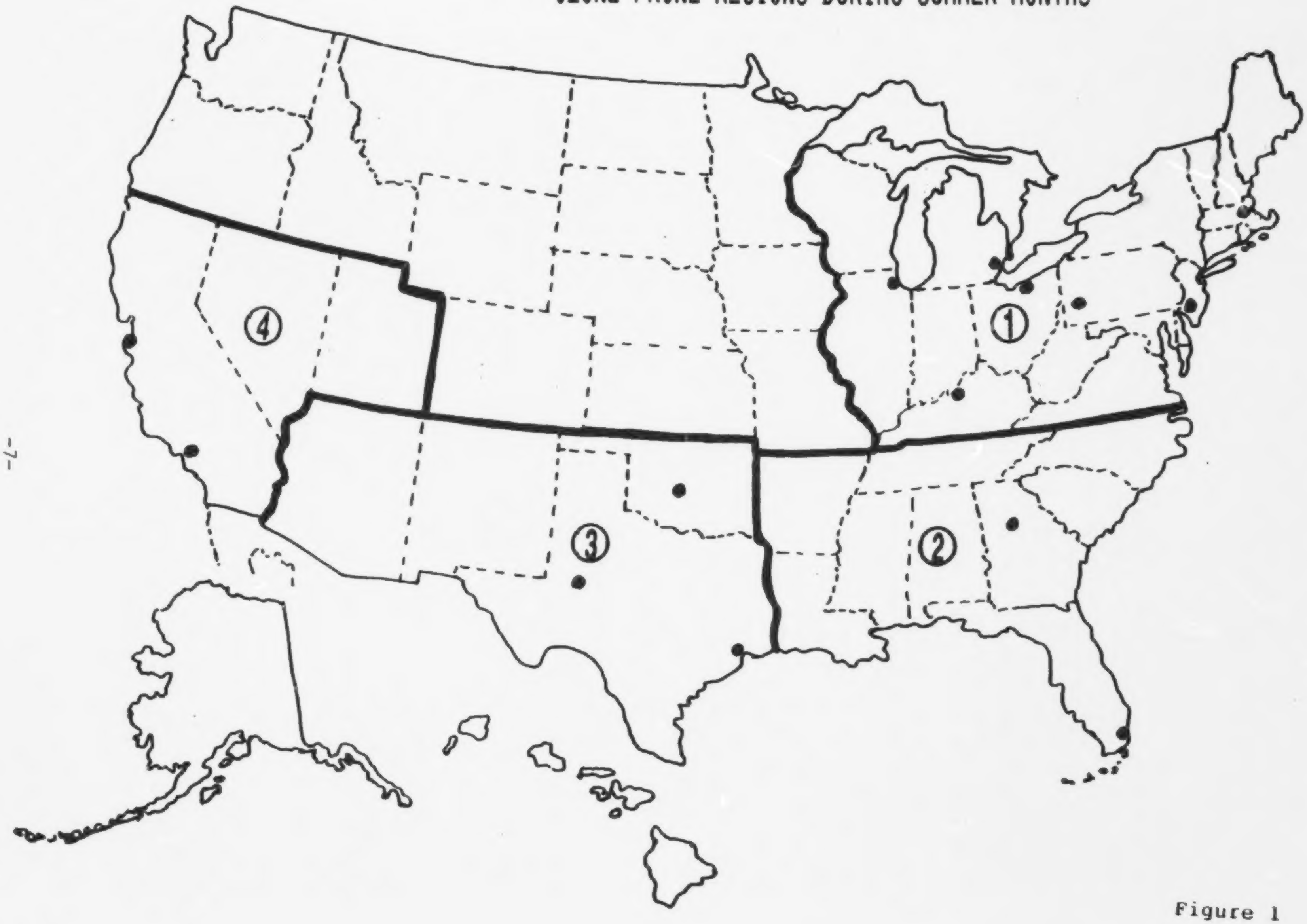

Figure 1

Figure 2

SUMMER REFUELING EMISSION FACTOR DISTRIBUTION FOR SELECTED CITIES*

EMISSION FACTOR (g/gal)

```
MIDPOINT    COUNT

 0.            0 +
  .20000       0 +
  .40000       0 +
  .60000       1 +x
  .80000       1 +x
 1.0000        0 +
 1.2000        4 +xx
 1.4000        5 +xxx
 1.6000        8 +xxxx
 1.8000       11 +xxxxxx
 2.0000       13 +xxxxxxx
 2.2000       10 +xxxxx
 2.4000       19 +xxxxxxxxxx
 2.6000       26 +xxxxxxxxxxxxx
 2.8000       35 +xxxxxxxxxxxxxxxxxx
 3.0000       37 +xxxxxxxxxxxxxxxxxxx
 3.2000       41 +xxxxxxxxxxxxxxxxxxxxx
 3.4000       56 +xxxxxxxxxxxxxxxxxxxxxxxxxxxx
 3.6000       65 +xxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxx
 3.8000      108 +xxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxx
 4.0000      134 +xxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxx
 4.2000      116 +xxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxx
 4.4000      107 +xxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxx
 4.6000      129 +xxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxx
 4.8000      128 +xxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxx
 5.0000      139 +xxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxx
 5.2000      151 +xxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxx
 5.4000      159 +xxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxx
 5.6000      139 +xxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxx
 5.8000      110 +xxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxx
 6.0000      124 +xxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxx
 6.2000       90 +xxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxx
 6.4000       76 +xxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxx
 6.6000       55 +xxxxxxxxxxxxxxxxxxxxxxxxxxxx
 6.8000       62 +xxxxxxxxxxxxxxxxxxxxxxxxxxxxxxx
 7.0000       72 +xxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxx
 7.2000       67 +xxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxx
 7.4000       70 +xxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxx
 7.6000       40 +xxxxxxxxxxxxxxxxxxxx
 7.8000       31 +xxxxxxxxxxxxxxxx
 8.0000       16 +xxxxxxxx
 8.2000        8 +xxxx
 8.4000        5 +xxx
 8.6000        4 +xx
 8.8000        1 +x
 9.0000        0 +

MISSING      528
TOTAL       3001
```

* Atlanta, Boston, Chicago, Cleveland, Detroit, Houston, Los Angeles, Louisville, Miami, Midland, Oklahoma City, Philadelphia, Pittsburgh, San Francisco

$$EF = -5.909 - 0.0949(\Delta T) + 0.0884(T_D) + 0.485(RVP)$$

RVP = ASTM Maximum allowable for the months involved.

rather than an upper limit. Its use has the effect of lowering the overall stringency of the test procedure from that represented by the fuel parameters.

A second stringency consideration is the fact that, as described in the technical report accompanying the original draft procedure[2], the temperature data used represented smoothed average values. Thus, for example, the dispensed fuel temperatures were five day averages, and did not contain the highs that daily values would give. Nor did they represent the daily maximun values, which the report indicated would typically be 4 to 7°F above the average.

Another factor described in the original report which has not been directly included in the procedure is the effect of fuel weathering on refueling emissions. The presence of weathered residual fuel in the fuel tank at the time of refueling, rather than unweathered fuel as used in the test procedure, would be expected to increase refueling emissions by perhaps 0.5 g/gal. EPA's decision not to use weathered fuel in the tank at this time is another factor reducing the overall stringency level of the refueling test. It would be possible to use weathered fuel and make some adjustment in the temperature parameters, but this change would have no beneficial effect on the test and would add the complexity of having to handle two different test fuels.

Given all these factors, the precise overall stringency of the test procedure is difficult to determine. EPA believes that it is sufficient to insure control at nearly all expected conditions, as was its original goal. The chief impact of more demanding test parameters is to increase required canister sizes to hold the increased amounts of generated vapors. This result is not undesirable, so long as no other system changes are required which might markedly increase the marginal cost of compliance. If this were the case, then more detailed analysis of test condition stringency might be justified to determine whether some relaxation might be appropriate.

2. Fuel Volatility

The draft recommended procedure specified that the test fuel have an RVP of 11.5 psi. This volatility represents the RVP of summer commercial fuel as used in current EPA emission factors test programs, as well as being the ASTM class C volatility upper limit for summer months in the ozone prone areas of the country. MVMA, in its comments, advocated that the fuel used in the refueling test procedure have the same RVP as that of EPA's current certification test fuel, i.e., 9 psi. MVMA understood and agreed with the Agency's desire to eliminate the present discrepancy between summer commercial fuel volatility and the current certification fuel volatility. MVMA's solution is, however, to limit commercial summer fuel to

9.0 RVP as opposed to specifying that the refueling test fuel volatility equal present commercial fuel volatility, as the recommended test procedure specified.

The issue of test fuel versus commercial fuel volatility is currently being examined by the Agency and EPA is studying fuel volatility to establish the best overall approach to dealing with this issue. Whatever the resolution of that process, EPA intends to adopt those results for refueling testing as well. The draft procedure used 11.5 RVP simply because it approximated the current in-use situation. That choice was not intended to represent resolution of the RVP issue. The procedure should more properly be viewed as potentially using a fuel with volatility anywhere in the range of possible options being considered by EPA at this time, i.e., anywhere from 8 to 11.5 psi.

An additional volatility concern was raised by Nissan. In its comments, Nissan expressed concern about variations in the RVP of test fuels and questioned how it can be controlled. This concern, i.e., the need to limit the weathering of test fuel in the fuel cart so as to minimize test variability, is shared by EPA. The revised procedure contains the requirement for the collection of a fuel sample and measurement of the RVP immediately prior to the measurement of refueling emissions. EPA recognizes that this is a worst case requirement with respect to its effects on test facility and personnel resources. EPA is open to all suggestions on equipment design or test data on the rate of fuel weathering in the fuel cart which would allow less frequent measurement of the RVP of the test fuel.

3. Fuel Dispensing Rate

The final area of comments with respect to the test parameters concerned the recommended value for the fuel dispensing rate. In the draft recommended procedure, the specified range of 8 to 10 gallons per minute (gpm) was identified as covering the majority of the refueling events while minimizing nuisance shutoff of the fuel nozzle. Several commenters took issue with this range for a variety of reasons. API stated that some vehicles can not be fueled at a rate as high as 8 to 10 gpm and that premature nozzle shut off at high fueling rates is associated with some filler neck designs. MVMA commented that spit-back is highly probable at a fueling rate of 10 gpm when the tank approaches the 95 percent full level, especially with a liquid seal. MVMA stated that CARB limits fueling to the 90 percent tank level at a fueling rate of 10 gpm, applicable with the 1987 model year. MVMA also stated that the specified fueling rate range of 8 to 10 gpm is too broad and recommended a fueling rate specification of 9.0 ± 0.2 gallons/minute to improve test repeatability and test-to-test and lab.-to-lab. correlation.

EPA agrees that the occurrence of nuisance shutoffs and fuel spillage may be a function of filler neck design when vehicles are fueled at high flow rates. However, it is EPA's belief that the design of a refueling control system which is capable of controlling premature nozzle shutoff and avoiding spit-back at expected in-use fuel dispensing rates is the responsibility of the motor vehicle manufacturers. Lacking spit-back control, fuel spillage from this source could be a major source of refueling emissions. Thus, a fuel filler system that prevents spit-back at the upper limit of the dispensing rate is integral to the effective control of refueling emissions.

At the same time, EPA recognizes the fact that, given vehicles designed to operate at current maximum values, gasoline marketing pressures would be expected to lead to increased in-use despensing rates in the future. In order to prevent such a situation, it is likely that some control, voluntary or otherwise, would be required over in-use dispensing rates.

EPA believes that a maximum dispensed fuel rate of 10 gpm is reasonable based upon current in-use conditions. The draft procedure reported that most refuelings take place at 10 gpm or less; also CARB has already specified 10 gpm for testing to demonstrate compliance with its refueling control program. Thus, 10 gpm will continue to be used as the approximate maximum flow rate.

Turning to the question of variability in test results between tests and/or between laboratories with respect to the rate at which fuel is dispensed, EPA believes that some variability in results can be attributable to this factor; i.e. fuel dispensing rate. EPA also believes that, in a refueling emissions test, the upper limit of the dispensing rate is normally the important criteria. In selecting a tolerance band for the fuel dispensing rate to address the test variability concern, EPA also recognized the need for the use of a value which would be achievable at a relatively low cost. EPA believes that a tolerance band of approximately 3 percent at a flow rate of approximately 10 gpm, i.e. ± 0.3 gpm, will achieve both objectives. Combining the selected tolerance band with the objective of holding the lower limit close to 10 gpm with a minimal exceedance of 10 gpm at the upper limit resulted in the flow rate specification of 9.8 ± 0.3 gpm. Testing conducted at EPA will normally dispense fuel as close to 10 gpm without exceeding the 10.1 gpm limit as possible, since this value would be expected to be the most difficult test condition.

B. Fuel Tank Heating

Heating of the fuel in the fuel tank was required in the draft recommended procedure to bring the liquid fuel and fuel vapors into equilibrium at the required test temperature. The test procedure included a method for heating the fuel tank using a single heat blanket which allowed the fuel vapor and liquid fuel to reach an equilibrium condition before testing. Concerns raised in the comments covered a wide range of areas. These concerns are summarized below.

In its comments, MVMA stated that the fuel tank configuration greatly influences the ability to heat the fuel and to achieve the 3°F vapor to liquid temperature difference required in the procedure. MVMA questioned the feasibility of the recommended procedure to achieve the required heating on a variety of tank configurations. MVMA requested that EPA demonstrate the feasibility of the procedure on several tank configurations. Data submitted by Ford showed an inability to achieve the required vapor temperature with a single heating blanket on a Mercury Lynx.

The question of how temperature measurements on in-use vehicles (use of an external thermocouple was proposed in the draft procedure) were to be made with plastic fuel tanks was also raised by MVMA. Another aspect of the fuel temperature measurement issue which was raised by commenters was the capability to read the true fuel temperature when heating a nearly empty fuel tank. The thermocouple would have to be very close to the heat blanket when the 10 percent fuel volume was being heated and MVMA stated that thermocouple readings could, as a result, be influenced by the heat blanket.

Comments on the subject of fuel tank heating also identified test-to-test variability as a concern. Toyota stated that the initial boiling point of 11.5 RVP fuel is under 88°F and that this fuel property, in combination with the specified temperatures of the fuel tank and of the fuel dispensing system, would result in high vapor losses and resultant test to test variability. Specifying a heating rate was recommended as a means of limiting the rate of boiling of the fuel and to avoid variability in test results caused by variability in the heating rate.

Concerns about the fuel tank heating procedure and temperature measurement requirements such as those expressed by the motor vehicle manufacturers were shared by EPA. As a result of its experience, EPA set out to revise the tank and dispensed fuel temperatures in an effort to eliminate the need for external tank heating and tank fuel temperature measurement.

Using the emission factor equation given earlier, alternative dispensed fuel and tank temperatures can be defined which would yield approximately the same emission conditions as the test parameters otherwise selected on the basis of test stringency. The approach used was to select a fuel tank temperature equal to ambient laboratory conditions (thus eliminating the need for tank heating) and to determine a dispensed fuel temperature yielding the same emission rate as did the initial test conditions. Temperatures developed from the equation were 80°F ± 2°F for the fuel tank temperature (80°F was selected because it is the temperature maintained in the EPA's Motor Vehicle Emission Laboratory vehicle soak area), 83°F ± 2°F for the dispensed fuel temperature and the requirement that the temperature of the dispensed fuel be 1° to 3°F higher than the soak area temperature. These temperatures resulted in a mean refueling emissions value of 7.29 g/gal which compared very favorably to the value of 7.26 g/gal for the original test conditions. The 80°F fuel tank temperature can be readily achieved without the need to heat or measure the temperature of the fuel in the vehicle tank through the process of soaking the vehicle at the required temperature for a pre-specified soak period. EPA chose a soak period of six hours as sufficient to accomplish this task.

Following the April 10, 1986 meeting, manufacturers provided comments on the revised temperature specifications. In their comments, they expressed strong support for the concept of selecting a fuel tank temperature equal to ambient laboratory conditions. However, a number of manufacturers commented that the ±2°F soak area tolerance was too restrictive. GM reported that maintaining tight control of room ambient temperature in its larger laboratories can be very difficult. EPA's main concern in designating the ± 2°F tolerance was to limit adverse impacts on test variability. In response to the comments, EPA performed additional analyses on the effects of test temperature tolerances on refueling emissions variability. The conclusion reached is that expansion of the soak area temperature tolerance band can be accommodated if accompanied by an adjustment in the dispensed fuel tolerance band to retain approximate equivalency in the refueling emissions tolerance band attributable to test variability in these temperatures. As a result, the fuel tank temperature is specified as 80°±3°F and the dispensed fuel temperature is specified as 81° to 84°F. EPA believes that maintaining the reduced dispensed fuel tolerance band will not be excessively burdensome. Under this approach, the dispensed fuel would only need to be heated to 81° - 84°F, which would substantially reduce any problems with respect to the boiling point of the fuel in the fuel cart and the associated changes in the fuel RVP. EPA believes that the use of these temperature specifications will alleviate the concerns expressed by the manufacturers without any reduction in the required control of refueling emissions.

C. Facility Requirements

The recommended refueling test procedure requires the use of a sealed housing for evaporative determination (SHED), similar to what is now used for evaporative emissions testing with minor alterations to accommodate fuel dispensing. The SHED is required for the actual refueling test and for loading of the canister to breakthrough. Comments on the facility requirements of the test procedure addressed: 1) the use of a SHED to determine canister loading to breakthrough; 2) the impact of the test on facility requirements; and 3) the location of the refueling hose and nozzle.

1. SHED Use for Breakthrough Determination

Commenters suggested the use of procedures other than a SHED to determine canister loading to breakthrough. It was pointed out that some contract laboratories which measure exhaust emissions do not have SHED equipment and would, therefore, be unable to perform refueling tests because of the lack of a SHED. The facility requirement impact (as discussed below) was also a concern for those facilities with SHEDs. A procedure involving repeated refuelings to load the canister without the need for a SHED was suggested as an alternative.

In addition to comments recommending the elimination of the use of a SHED when loading the canister, comments were made recommending changes to the SHED loading procedure itself. MVMA stated that the procedure should be written so as to prevent the continued forcing of vapors through a canister which is loaded to breakthrough. MVMA believes that the procedure as proposed would load the canisters past breakthrough, and as a solution recommended using a reduced fueling rate, e.g., 3 gallons/minute, during canister loading to breakthrough. MVMA also recommended that the sample pick-up point for detecting breakthrough be close to the canister rather than remotely mounted in the SHED as specified in the recommended procedure. MVMA believes that reducing the response time for breakthrough detection will prevent continued forcing of vapors through a canister already loaded to breakthrough.

Responding first to the basic issue of needing a SHED to detect breakthrough, EPA agrees that a canister loading approach which would not require the use of a SHED to determine canister breakthrough is desirable so as to simplify testing and reduce resource requirements. Use of the SHED was proposed by EPA so as to address the following concerns associated with the use of a sample pick-up located at the canister. First, that a small transient puff of vapor from the canister, prior to breakthrough, could be interpreted as breakthrough and thereby result in incomplete loading of the canister. Second, that relatively small air currents around the vehicle, as could occur in a large room, could dissipate breakthrough vapors and lead to delayed detection of breakthrough.

A small quantity of data recently collected by EPA using current evaporative emissions canisters suggests that small premature puffs of vapor may not be a significant concern. There is, however, no way of telling whether this data is applicable to the larger and possibly reconfigured canisters which are anticipated for use with onboard refueling systems. There is also no information on the effects of air currents around the vehicle on breakthrough detection. EPA continues to believe, therefore, that the SHED needs to be used in determining canister breakthrough loading. At the same time, the Agency would welcome the submission of further data on this area which might lead to a non-SHED based approach.

MVMA's concern with the SHED procedure is that breakthrough will occur significantly before detection because of the sample pick-up location. As a result of the detection delay, MVMA is concerned that a fueling rate of 10 g/min will cause a significant amount of additional vapor to be transmitted to the canister beyond the actual breakthrough point. EPA agrees that detection lag will result in some degree of canister loading beyond breakthrough and that the degree of loading beyond breakthrough will depend on the refueling rate. However, since the objective of the canister loading procedure is to achieve loadings to at least breakthrough, this fact of itself is not troubling. What is of concern is the increased amount of variability in breakthrough measurements at high fuel flow rates. For this reason, some reduction in the fueling rate would be acceptable provided loading to at least breakthrough was achieved. Testing conducted by EPA at a fueling rate of 3 to 4 gallons per minute has shown that repeatable loading conditions should result. The fueling flow rate during the canister loading procedure will, therefore, be specified as 3-4 gallons/minute.

2. Testing Capacity

Commenting on the impact of the test on facility requirements, Toyota stated that adoption of the recommended refueling test procedure would result in either a significant reduction in the testing capacity of existing facilities or would require significant facility expansion to retain present testing capacity. The costs related to the modification and/or construction of expanded test facilities was a significant issue to a number of commenters.

EPA recognizes that incorporation of the refueling test procedure, or for that matter any other new testing requirement, into the existing emissions testing procedure will impact test facilities to some extent. EPA, like the manufacturers, is desirous of holding to a minimum the impact of the procedure on facility requirements. EPA is making every effort to minimize the impact whenever possible in developing the test procedure. In fact, the revised procedure, which will be described further below, has a much lower facility impact than did the previous draft. All comments on how the impact on facility requirements can be further minimized are encouraged and welcomed.

In the area of costs, EPA recognizes that some expenditures will be necessary to expand test facilities to accommodate the demands of incorporating the refueling test procedure. However, it appears that, as a part of overall cost, these impacts will be relatively small. For example, values used by the Motor Vehicle Manufacturers Association, when viewed as a cost per production vehicle, represent only approximately 30 cents per vehicle. Even these values would be expected to decline in the face of the procedural revisions being described in this document.

3. Refueling Hose Location

The draft procedure specified that the fuel dispensing hose and nozzle be located inside the SHED. One commenter questioned whether non-permeable fuel hoses would be required; fuel hose permeability, nozzle leakage, and nozzle-to-fuel hose joint leakage may cause a SHED contamination problem.

During SHED background and retention validation tests conducted at EPA's Motor Vehicle Emission Laboratory, contamination problems were experienced as a result of the location of the fuel dispensing hose and nozzle inside the SHED. This problem was resolved by moving the hose and nozzle outside of the SHED and providing access to the vehicle's fill neck by a boot so that only the nozzle tip enters the SHED. The specific criteria developed for the boot are: that the aperture through which the nozzle tip passes seals against the tip when the nozzle is inserted and closes to form a vapor tight seal when the nozzle is not in place; that the boot be flexible and relatively long so as to avoid the need for precise locating of the vehicle in the SHED; and the boot be large enough to facilitate free passage of the nozzle through the boot and full operation of the nozzle inside of the boot. Location of the nozzle and fuel hose outside of the SHED has solved the contamination problems. The procedure has been modified to require the use of equipment for refueling with the refueling hose and nozzle located outside the SHED.

D. Requirement for Loading Canister to Breakthrough

Commenting on the requirement for canister loading, two commenters took issue with the need to fully load the canister to breakthrough. MVMA and Toyota stated that forced loading of the canister to breakthrough is not representative of in-use vehicle operation and should, therefore, not be part of the test procedure. These comments also claimed that loading of the canister in this manner will have a negative impact on exhaust emissions, on fuel economy and on driveability. MVMA stated that full canister loading followed by one prep LA-4 will significantly add to the difficulty of complying with exhaust emissions standards and in meeting fuel economy objectives and will result in the collection of exhaust emissions and fuel economy values under non-representative operating conditions. MVMA also believes that full loading of the canister removes any incentive to provide a safety margin in canister sizing because excessive hydrocarbons have to be processed during purging and this will cause driveability problems. One commenter pointed out that the proposed procedure did not require loading to breakthrough of the evaporative canisters in non-integrated onboard systems.

EPA believes that loading canisters to breakthrough is an important requirement of the procedure so as to demonstrate that the system will adequately purge the canister from a fully loaded condition. The need to demonstrate this capability in the test procedure stems from the wide variations which exist in the method of operation of in-use vehicles. Since the degree to which a canister is purged prior to refueling is dependent on vehicle operations preceding refueling, it is reasonable to expect that wide variations in the degree of canister purge can also exist in in-use vehicles. Vehicles used infrequently and in short trip operations will experience reduced canister purging while accumulating hot soak emissions after each trip and repeated diurnal loadings because of infrequent operation. As a result, these in-use vehicles can be expected to experience forced loading of the canister to breakthrough or saturation. Forced canister loading to breakthrough in the test procedure is, therefore, not unrepresentative of an event which can occur on an in-use vehicle. Data available to EPA indicate that the canister system does not undergo permanent adverse effects by being highly loaded and quickly recovers its capacity when vehicle operating conditions provide additional purge. Loading of a canister to breakthrough results in a readily achievable and repeatable canister loading condition. Retention of the loading to breakthrough requirement in the procedure thus provides a useful, readily identifiable point for beginning testing.

It is important to note that loading the canister to breakthrough is regarded by EPA as a minimum loading condition before testing. If, because of its in-use operating factors, a vehicle comes in for testing loaded beyond breakthrough, it will be tested as received. If systems are properly designed, such occurrences should be rare; but if systems are not properly designed and frequently operate beyond the breakthrough point, then this is a consequence of the design and the systems still ought to be tested in that condition.

Although some of the commenters felt that loading the canister to breakthrough would have an adverse impact on driveability, exhaust emissions, and fuel economy, and therefore should not be included in the test procedure, EPA does not agree. First, since canister loading to breakthrough will occur on in-use vehicles, manufacturers will have to accommodate this condition in their system designs regardless of test requirements. Manufacturers will have to design their systems to operate satisfactorily with respect to both canister purge and driveability because of in-use considerations. As for exhaust interactions, EPA has always expected that evaporative systems should be able to begin the evaporative test procedure from a loaded condition and expects to introduce this requirement apart from any onboard actions. The presence of an onboard canister could increase the amount of purge vapors under loaded conditions, but not to an unmanageable degree. As for fuel economy, EPA agrees that impacts on fuel economy measurements should be avoided. The simplest option would be to allow those manufacturers who believe that loading the canister to breakthrough will have a negative impact on fuel economy to omit the canister loading step for the fuel economy test. If this approach were unsatisfactory, then a CAFE adjustment might have to be considered.

One revision was made to the canister loading procedure as a result of the comment which pointed out that there was no loading procedure for the evaporative canister in non-integrated systems. Omission of this step in the procedure was an oversight since the intent of the procedure was to include a loading step for the evaporative canister in non-integrated systems. A step will, therefore, be added to the procedure requiring the loading to breakthrough of the evaporative canister in non-integrated systems prior to the vehicle preconditioning. As with refueling canisters, this step will require the use of the SHED to determine the breakthrough point.

E. Vehicle (Canister) Conditioning for Performance of Refueling Emissions Control Test

Background

The test sequence proposed for refueling emissions added two new tests designed to check the capacity and purge capability of the refueling control system, respectively. Both of these tests depended upon canister preconditioning steps for their proper functioning.

The refueling capacity test was designed to ensure that the overall vapor control capacity of the canister was sufficient for a complete fill-up, i.e. from 10 percent of tank volume to at least 95 percent of tank volume. Certification test vehicles were expected to arrive at the test site with canisters purged to a level commensurate with a nearly empty tank. Prior to testing, the fuel tank would be drained and filled to 10 percent of capacity with test fuel. Since in-use vehicles could arrive in any condition, preconditioning by 50 miles of driving using test fuel on either the durability driving schedule or equivalent urban driving was proposed. Following the 50 miles of driving, the fuel tank would be drained and fueled to 10 percent of capacity. Following this preconditioning, the actual refueling test would then be performed to verify that the refueling system indeed had adequate capacity to handle essentially a full refueling.

The second, or purge, test began with a drive-down sequence on the dynamometer, consisting of sequential Urban Dynamometer Driving Schedules (UDDS or LA-4), alternating with one hour hot soaks. This sequence was intended to use fuel and allow refueling canister purge, in order to subsequently perform a partial refueling with an amount of fuel large enough to adequately test the system's purge capability. To do this, the UDDS soak sequence would be repeated until approximately 30 percent of the tank fuel capacity had been used. A refueling test would then be conducted as with the capacity test, except that the refueling amount would approximately correspond to the amount of fuel consumed in the drive-down. The purpose of this stage was to demonstrate that the refueling control system had adequate purge capacity to purge accumulated refueling vapors.

Comments

Since the condition of the refueling canister prior to any refueling test is very important, it is not surprising that considerable comment was directed at the various conditioning steps in the draft procedure. Commenters generally believed that the 50 mile drive for in-use vehicles was inadequate, and they opposed the use of a conditioning procedure for in-use vehicles different from that used on certification vehicles. Commenters also expressed concerns with respect to the capability of the 30 percent drive down to prove the purge capability of the system.

Commenters suggested several alternative procedures for conditioning of the canisters prior to performance of the refueling capacity test. For certification vehicles MVMA suggested actual* vehicle driving while Toyota suggested starting with a full fuel tank and driving either 14 hours on the durability mileage accumulation procedure or 80 hours of UDDS/hot soak operation. The American Petroleum Institute (API) suggested the use of a 50 mile drive for certification vehicles as had been proposed for in-use vehicles.

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* "Actual", while not defined, seemed to imply operation of the vehicle either on a test track or on the road using an operating schedule which would reflect actual consumer driving patterns.

For capacity testing of in-use vehicles, both MVMA and Toyota suggested driving out the fuel contained in the fuel tank at the time that the vehicle entered the test program. MVMA suggested driving 75 miles for each 1/4 tank volume contained in the fuel tank. Toyota suggested driving the vehicle until 10 percent fuel volume remained in the tank.

Commenters also questioned the 30 percent drive-down associated with the canister purge test. They suggested that actually driving out a whole tankful of fuel might be the only reliable way to verify proper system purge characteristics. EPA itself had indicated concern with respect to the adequacy of the 30 percent drive-down because of the non-linear nature of canister purging with time. The draft procedure contained EPA's suggestion that a full drive-down might be required.

In order to effectively respond to all the concerns over canister preconditioning which have been raised, EPA has undertaken an extended analysis of canister purge characteristics and vehicle operating patterns. From this analysis the Agency has derived a revised approach to preconditioning and testing refueling control canisters. This approach is greatly simplified compared to the draft procedure, and provides a more accurate way to assess the ability of refueling control systems to perform properly in actual use. The results of EPA's analysis are presented in the following sections.

Analysis

1. Canister HC Purge Characteristics

To develop an understanding of how canisters purge, EPA performed a series of tests on evaporative emission control canisters. Some of the canisters had been in use (aged) on durability data vehicles and were furnished by Chrysler, Ford, GM and Nissan while others were new units purchased from dealers. One relatively large canister, constructed by EPA, was also tested. The details of the testing and the test results are shown in the Appendix. The overall results are summarized below.

Two basic steps were used in testing the desorption characteristics of carbon canisters. The first involved loading the canister to an appropriate level with refueling vapors. The second was to draw air over the carbon bed to purge it of its hydrocarbon load. Purge curves were developed by monitoring the change in hydrocarbon load as a function of the volume of purge air pulled over the carbon bed.

The key results of the testing are shown in Figure 3. Shown are characteristic purge curves for the various canisters

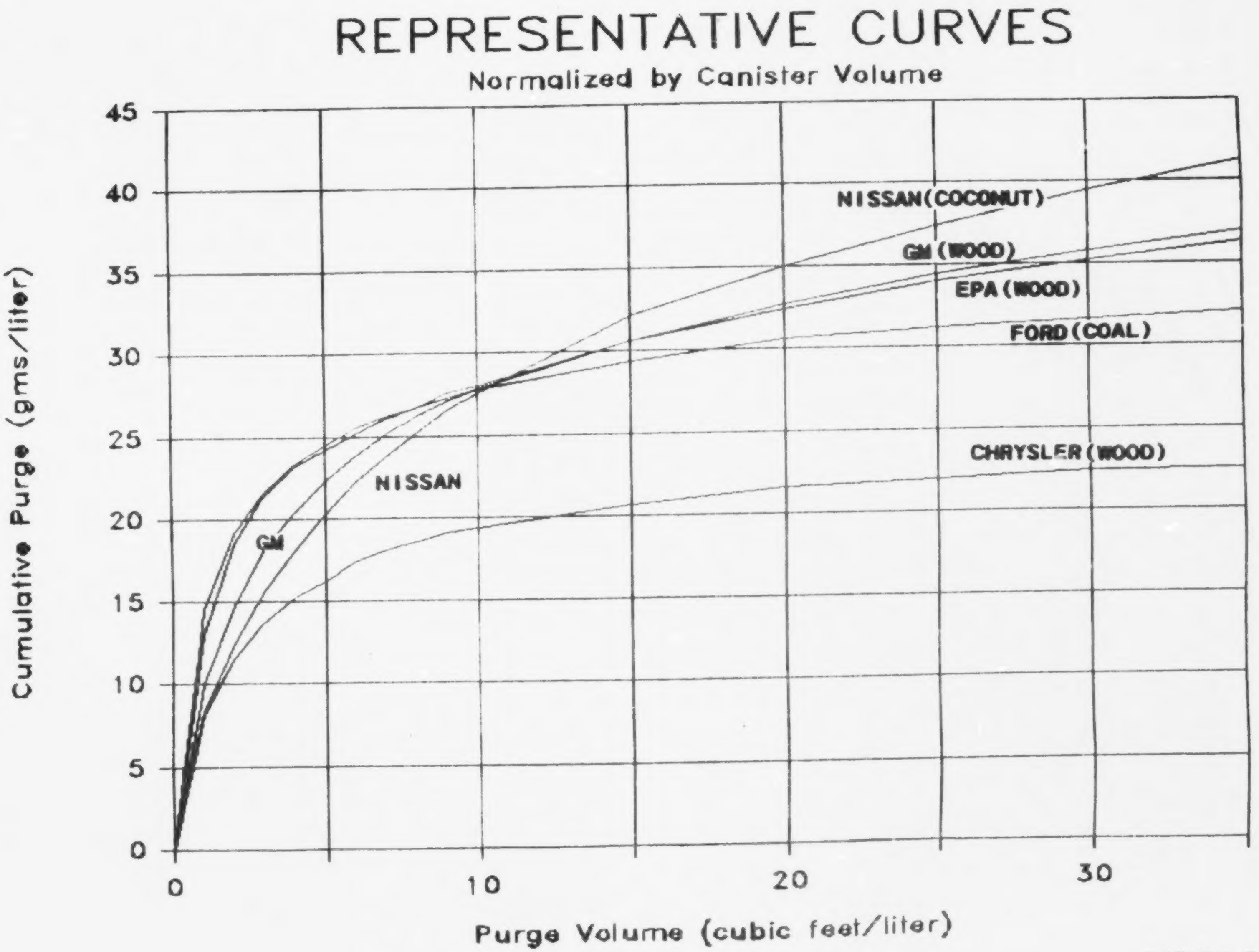

REPRESENTATIVE CURVES
Normalized by Canister Volume
Cumulative Purge (gms/liter)
0
5
10
15
20
25
30
35
40
45
Purge Volume (cubic feet/liter)
0
10
20
30
NISSAN(COCONUT)
GM (WOOD)
EPA (WOOD)
FORD (COAL)
CHRYSLER (WOOD)
NISSAN
GM

FIGURE 3

expressed as the weight of hydrocarbons removed from the canister versus the volume of air drawn through the canister. The test results have been normalized to a canister volume of one liter to provide a standardized basis for comparisons.

In reviewing the results of this testing, EPA decided that the results of the tests on the Chrysler canister should not be used for subsequent analysis. This canister showed a substantially lower storage capacity than the other canisters, for reasons which were never identified. In any event, a canister with such a small storage capacity per unit volume of charcoal would not be expected to be a reasonable choice for use in refueling control systems. To characterize the range of characteristics exhibited by the other three canisters, EPA has used the Nissan and Ford curves in its analysis. At this time, EPA does not know how representative of all canister designs these results are, nor how much improvement in canister performance could be gained by attempts to optimize charcoal performance. However, these questions are not critical in relation to the primary goal of describing general system characteristics and designing appropriate test techniques.

2. Vehicle Operation

Evaluation of in-use vehicle operational patterns important to an onboard refueling test program requires consideration of typical daily events which contribute to the loading and unloading of the canister. Hydrocarbon vapors generated during evaporative diurnals and hot soaks along with vehicle refuelings constitute canister loading events. Vehicle drive events cause canister unloading.

On the basis of typical driving patterns, in-use vehicles are employed under widely varying conditions. As a result of this variability in daily operational trips, the loading, at any selected time, of a HC vapor control canister, whether it be a refueling control canister or an evaporative control canister, will also vary. At one extreme is the condition of multiple days wherein the vehicle is not driven at all. Under this non-driven condition, the canister will experience repeated daily diurnal loadings of HC vapor and will eventually reach a fully loaded (saturated) condition; i.e., the canister's capacity to adsorb and retain HC will be reached. At the other extreme in the range of daily operational characteristics is continuous long trip operation. Under these conditions, the canister will undergo continuous purging and the amount of HC stored in the canister would approach zero.

Between these limits lie a wide variety of daily vehicle usage patterns. Typically, vehicle usage patterns might include two employment related trips per day and one or more trips for other purposes. Under multiple vehicle trip per day operations, the canister will undergo purging while the vehicle is being driven and loading due to hot soaks and the daily diurnal while the vehicle is parked. To analyze overall system performance, EPA constructed a simple model of canister behavior. Using the canister purge curves described above, the model was able to track canister performance for both Ford and Nissan type canisters.

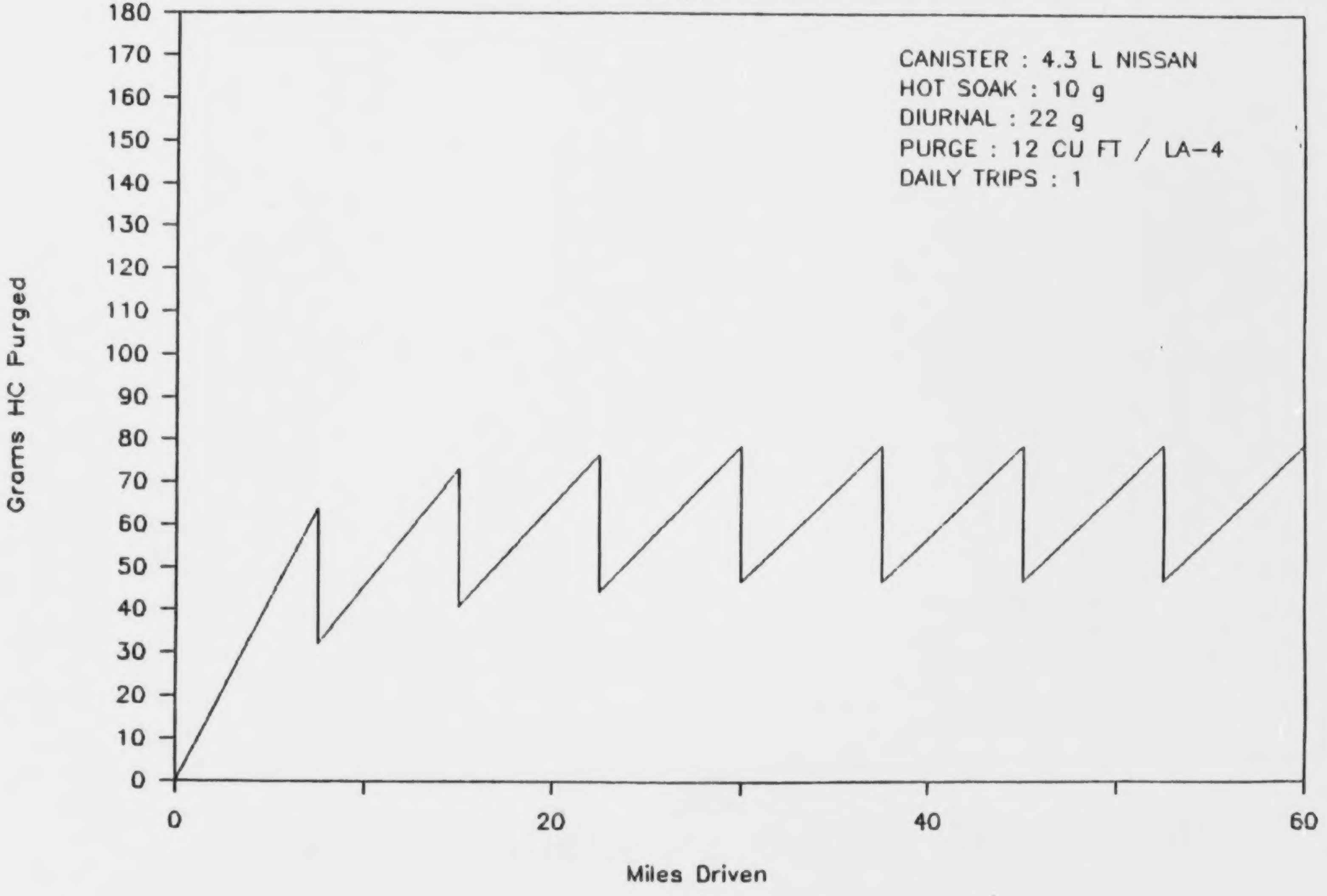
In the model, each daily trip is considered to be equivalent to one LA-4; i.e., 7.5 miles of vehicle operation. The purge rate is expressed as the volume of purge air, in cubic feet, per LA-4. The reference information stored in the model is the characteristic canister purge curve for one liter Ford and Nissan canisters. The input variables employed are desired canister size and type, purge air volume per LA-4, uncontrolled hot soak and diurnal loadings in grams, and the number of trips per day. The outputs from the model are tabulations of the running tally of the canister purges and loadings relative to miles driven plus other parameters which can be derived from these figures (e.g., amount of HC purged per mile). Running losses, if any, are treated as going directly to the engine and not impacting loading or purging of the canister. This assumption is not appropriate for all current evaporative control system designs, but EPA believes that such designs will not be found on future systems because of their adverse impact on canister purge. In addition, diurnal loadings are treated as a constant, neglecting the fact that, for example, immediately following a refueling, the fuel tank would be full and essentially no diurnal emissions would be generated. This means that the results from the model are representative of conditions after part of the fuel has actually been used up and not to be interpreted as the full time history of events beginning with a full tank.

The results from a typical run of the computer model are shown in Figure 4. In this case, a simple pattern is illustrated consisting of a single daily drive followed by a hot soak and a diurnal. The model indicates that after only a few repetitions of this pattern, an equilibrium is reached between purging and loading. This equilibrium indicates the vapor storage capacity available for refueling control. Note that continuing to operate on this pattern produces no further progress toward the fully purged capacity of the canister.

One of the key effects on system performance in this example is the daily driving pattern which is assumed. Figures 5 through 7 illustrate the effect of using two, three or four assumed trips per day instead of one. As can be seen from

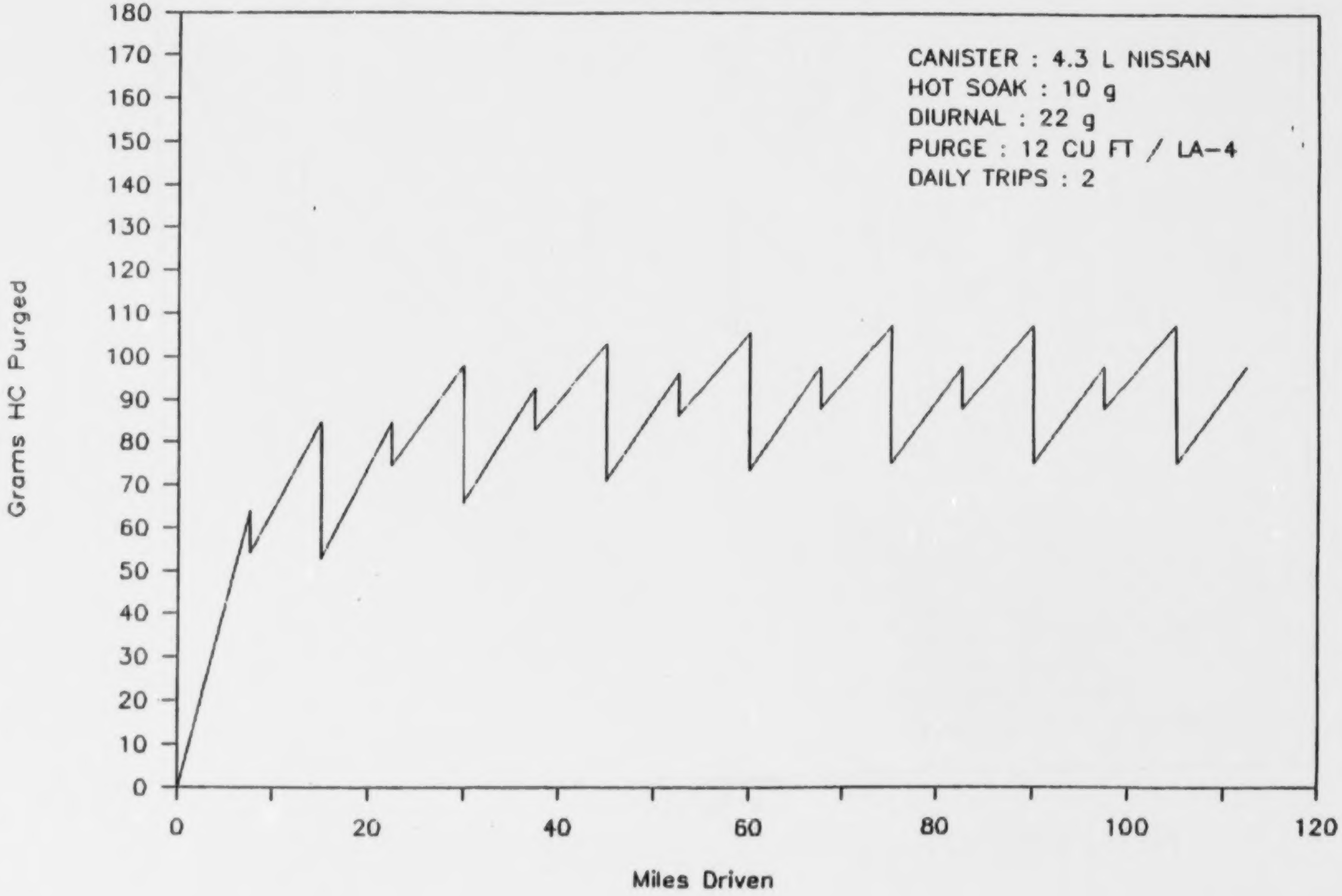
CANISTER PURGE VS CYCLIC OPERATION

FIGURE 4



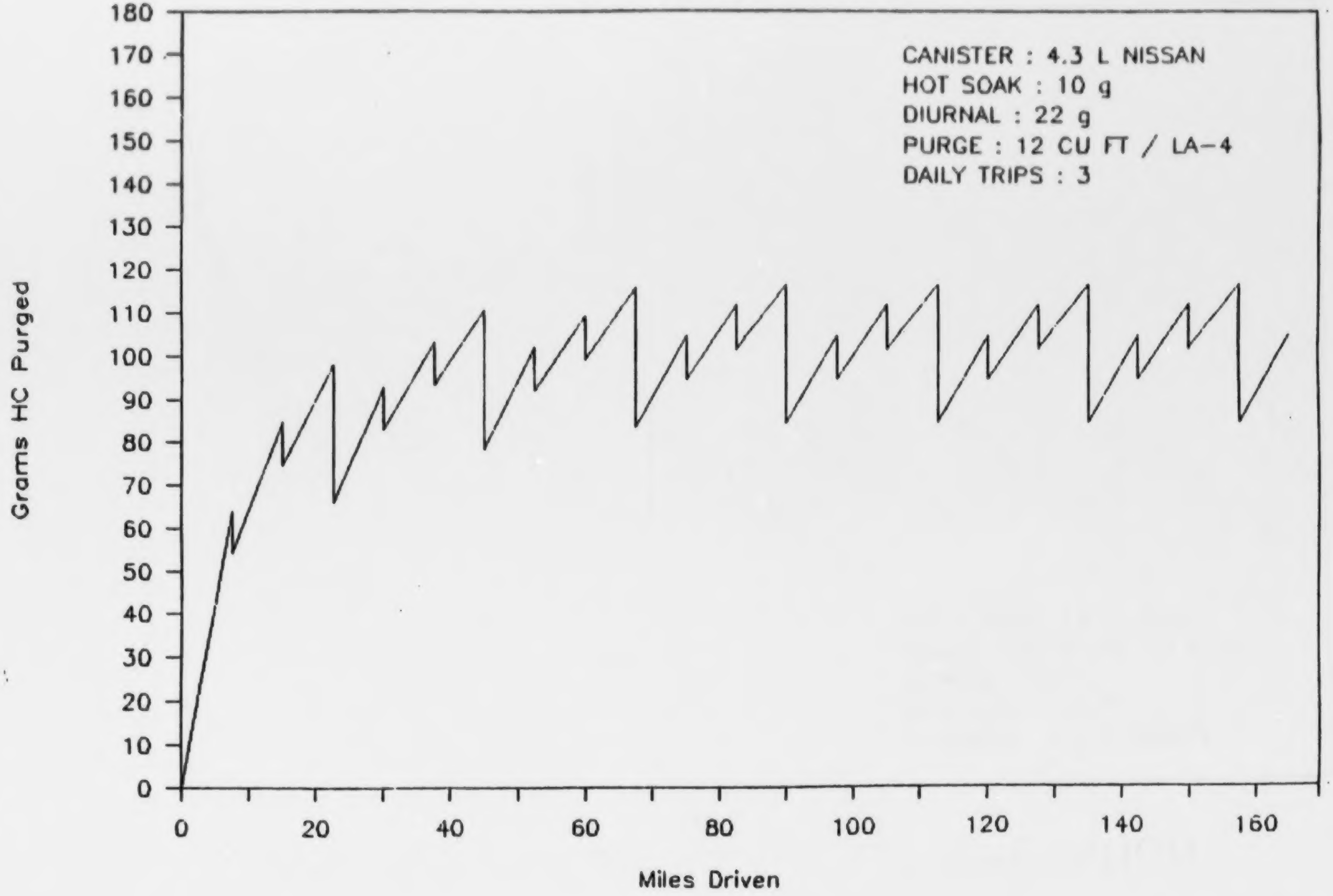
CANISTER PURGE VS CYCLIC OPERATION

FIGURE 5



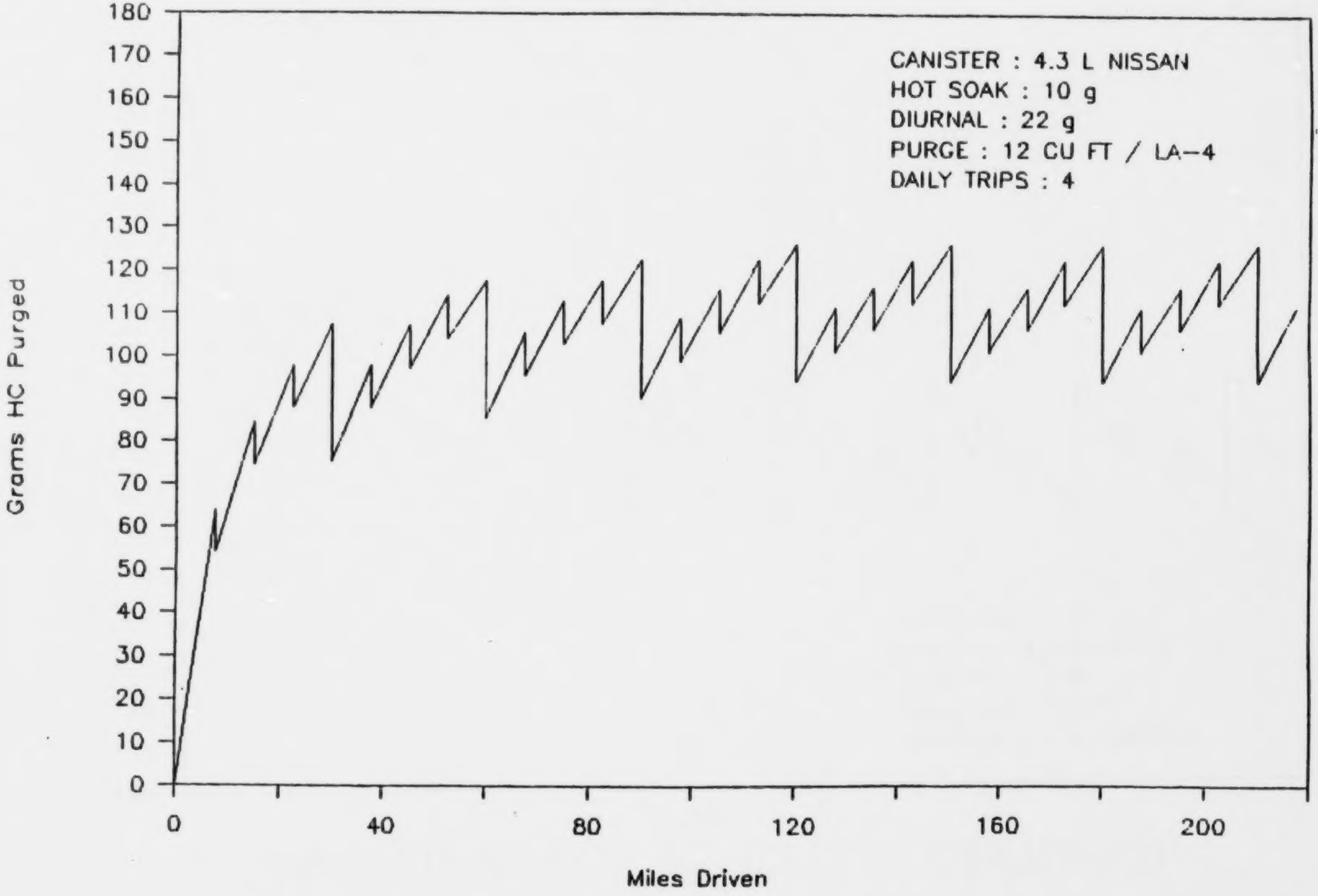
CANISTER PURGE VS CYCLIC OPERATION

FIGURE 6



CANISTER PURGE VS CYCLIC OPERATION

FIGURE 7



these figures, vehicles operated on either a one or two trip per day cycle will possess lower refueling capacities than vehicles operated under a three or four trip per day cycle. On the other hand, it is the case for all of the driving patterns that the canister reaches an equilibrium condition after only a few repetitions of the daily operating pattern. These results, incidentally, have been derived for a Nissan type canister because the Nissan canister shows the greatest sensitivity to driving patterns and makes the clearest example. Ford type canisters respond to driving patterns, but to a lesser degree.

Following initial evaluation of the effect of driving patterns, EPA chose to do its subsequent modeling based upon a three trip per day sequence. As will be seen below, this pattern has also been used in the test procedure preconditioning sequence development. Three trips per day closely resembles the value of 3.05 trips per day in the EPA MOBILE3 model for determining the effects of mobile source emission standards on pollutant inventories. From the above modeling results, however, it is clear that this represents a less demanding requirement than that of a one or two trip per day sequence. The overall effect of this choice upon test procedure stringency has not been quantified.

3. Effect of Purge Rate

For a given vehicle, the other key operating variable which affects refueling system performance is the purge rate. The refueling model shows that, holding canister size constant, the equilibrium level (which represents the available refueling capacity) can be increased or decreased by changing the air purge rate. These effects are illustrated in Figures 8 and 9.

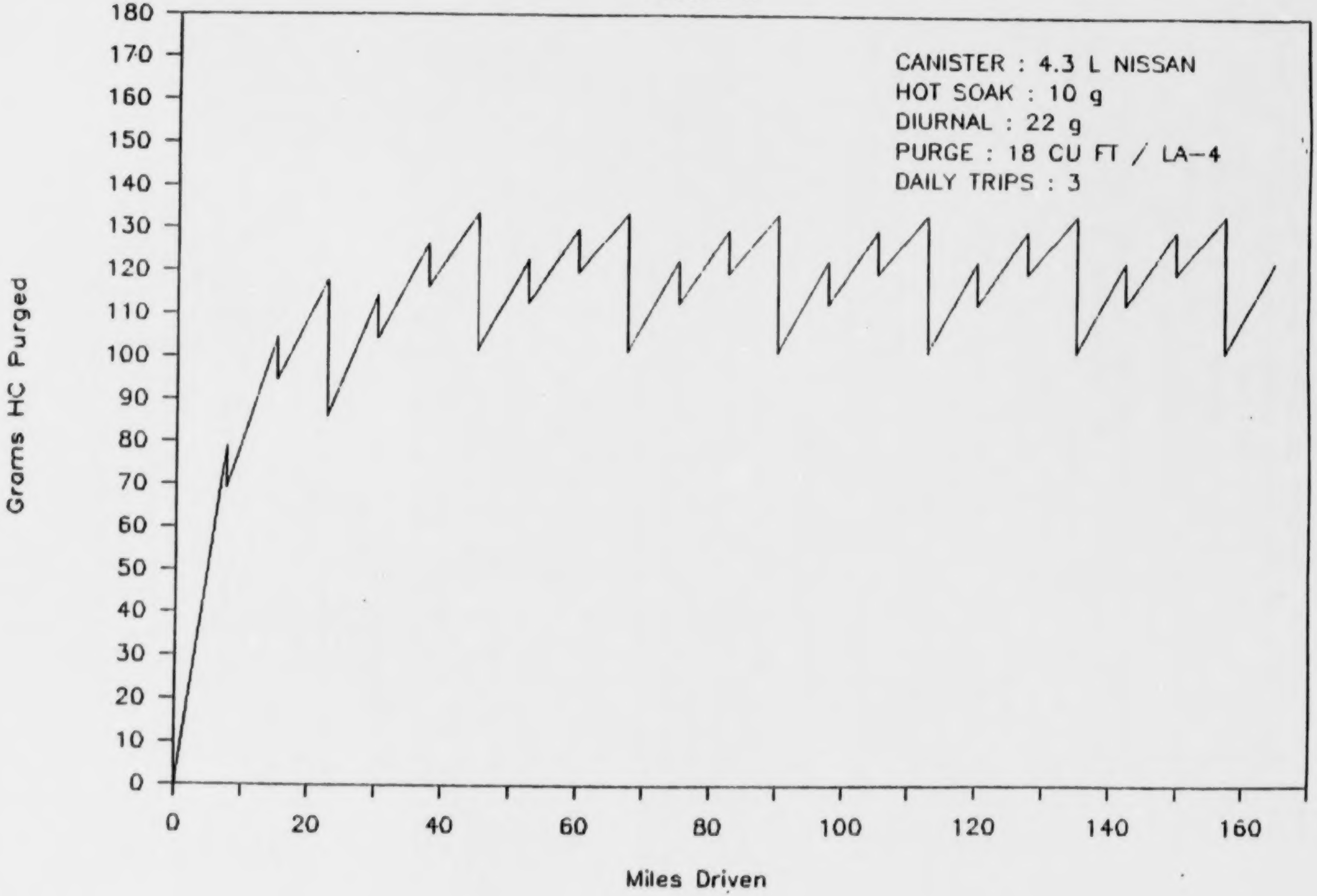
The effect of increasing the purge air rate in the example used above by 50 percent is shown in Figure 8. The increase in purge air rate results in an increase in the amount of hydrocarbons which are purged from the canister at equilibrium; i.e., an increase in refueling capacity. Conversely, it is shown in Figure 9 that a 50 percent decrease in purge air rate results in a reduction in the hydrocarbon purge level at equilibrium; i.e., a reduction in refueling capacity.

4. Canister Sizing

Having developed a basic model of refueling system loading and purging, required canister sizing for refueling operations was analyzed. The required refueling vapor capacity for a given vehicle was determined using the uncontrolled emission factor equation developed in EPA's refueling emission baseline study (Refueling Emissions from Uncontrolled Vehicles; EPA-AA-SDSB-85-6). An entertainment factor of 20 percent (based upon early test results with a liquid seal system) and a safety margin of 10 percent were added to this basic rate to estimate overall required design capacity.

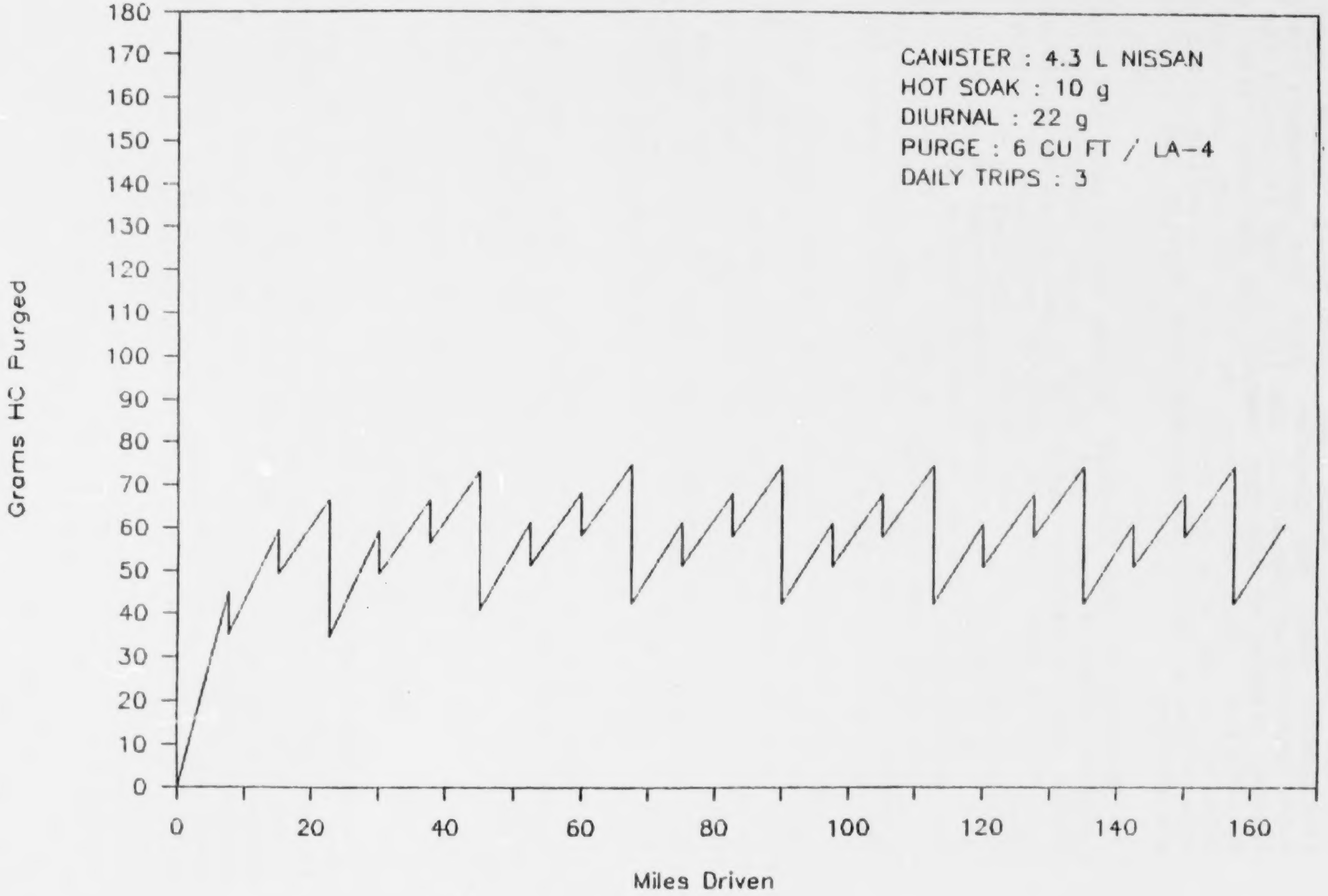
CANISTER PURGE VS CYCLIC OPERATION

FIGURE 8



CANISTER PURGE VS CYCLIC OPERATION

FIGURE 9



The required capacity was then related to the equilibrium level of the canister in the EPA model. More specifically, required canister size was determined based upon the requirement that the canister have the necessary refueling vapor capacity at the end of the first trip following the daily diurnal loading of the day wherein the canister first reached equilibrium. This means that, at equilibrium, the vehicle is expected to be able to handle a full refueling after having experienced a daily diurnal and then driving one trip to the gas station.

Because of the tradeoff between purge rate and effective canister capacity described above, equal canister equilibrium levels and, therefore, refueling capacity can be achieved from a relatively wide range of canister sizes and a corresponding range of purge air flow rates. Canister size, for equal refueling capacity, is inversely proportional to purge air flow rate. This relationship is shown in Figures 10 through 13 for four different vehicle types: a small car, an average car, a full-size dual-tank light-duty truck, and a typical heavy-duty gasoline truck. The specific characteristics assumed for each vehicle are given in Table 3.

A couple of common characteristics are apparent from these figures. First, when the purge rate is relatively high the Ford type canisters generally require somewhat greater canister volume than do the Nissan type canisters. However, as the purge rate is decreased to the low end of the purge rates investigated, the Nissan type canisters tend to be larger than the Ford type. Second, the curves are fairly flat over a broad range of purge rates, followed by a rapid upturning in canister size at low purge rates.

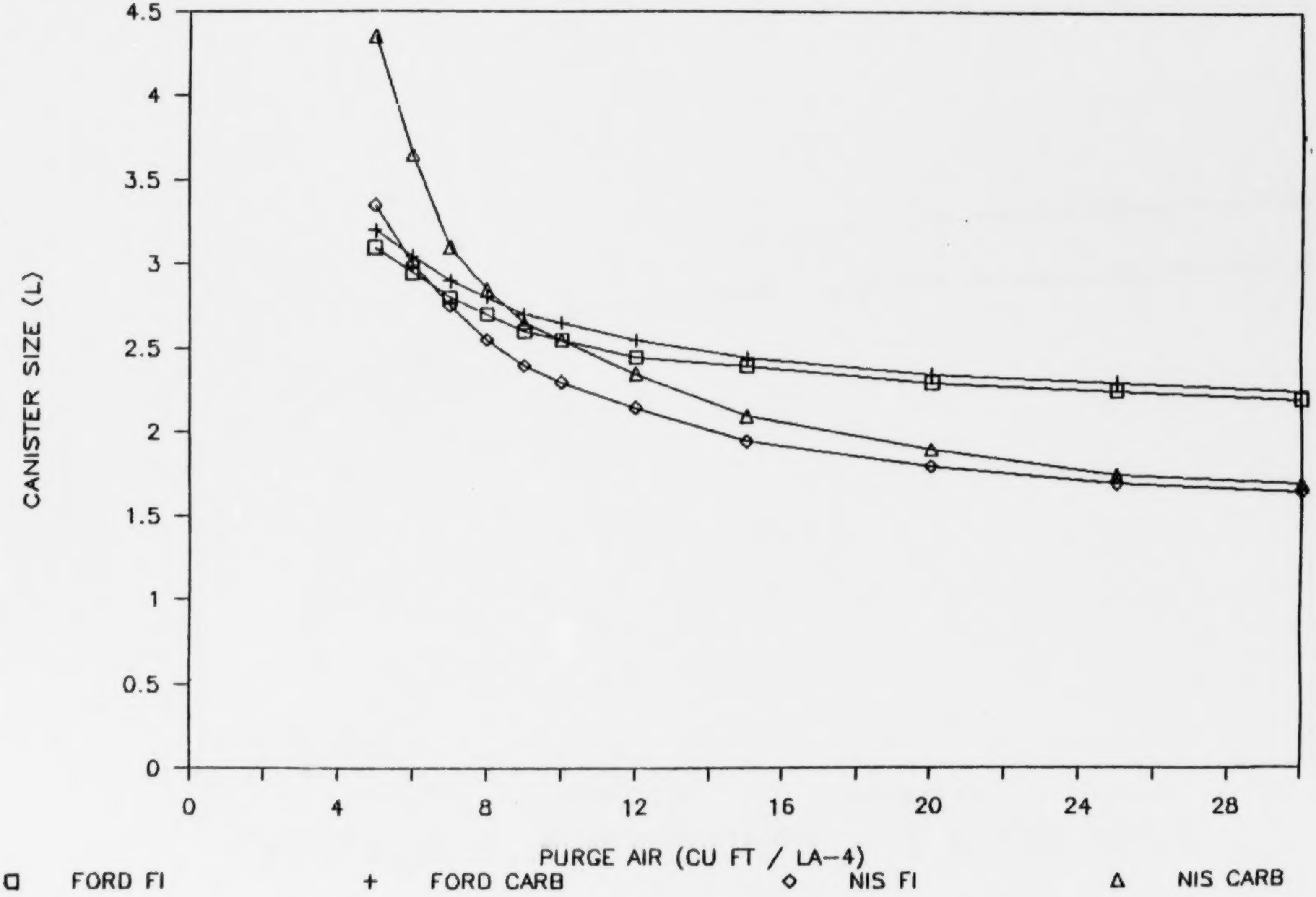
Since both diurnal and refueling loads, which are the dominant vapor sources, are proportional to fuel tank size, it is possible to normalize the results for all four vehicles and produce a single family of curves. Figure 14 shows the relationship between canister volume per gallon of fuel tank capacity and LA-4 purge rate per liter of canister volume.

5. Refueling System Effects on Engine Operation

Recognizing that both canister size and purge air flow rate can vary widely, it is appropriate to investigate those factors which could establish boundaries on these parameters. Since a small canister is desirable from both a cost and a packaging perspective, designers can be expected to use the smallest canister possible. Since canister size decreases as purge air flow rate increases an investigation of potential upper limits for purge air flow rate is warranted.

CANISTER SIZE VS PURGE AIR FLOW RATE

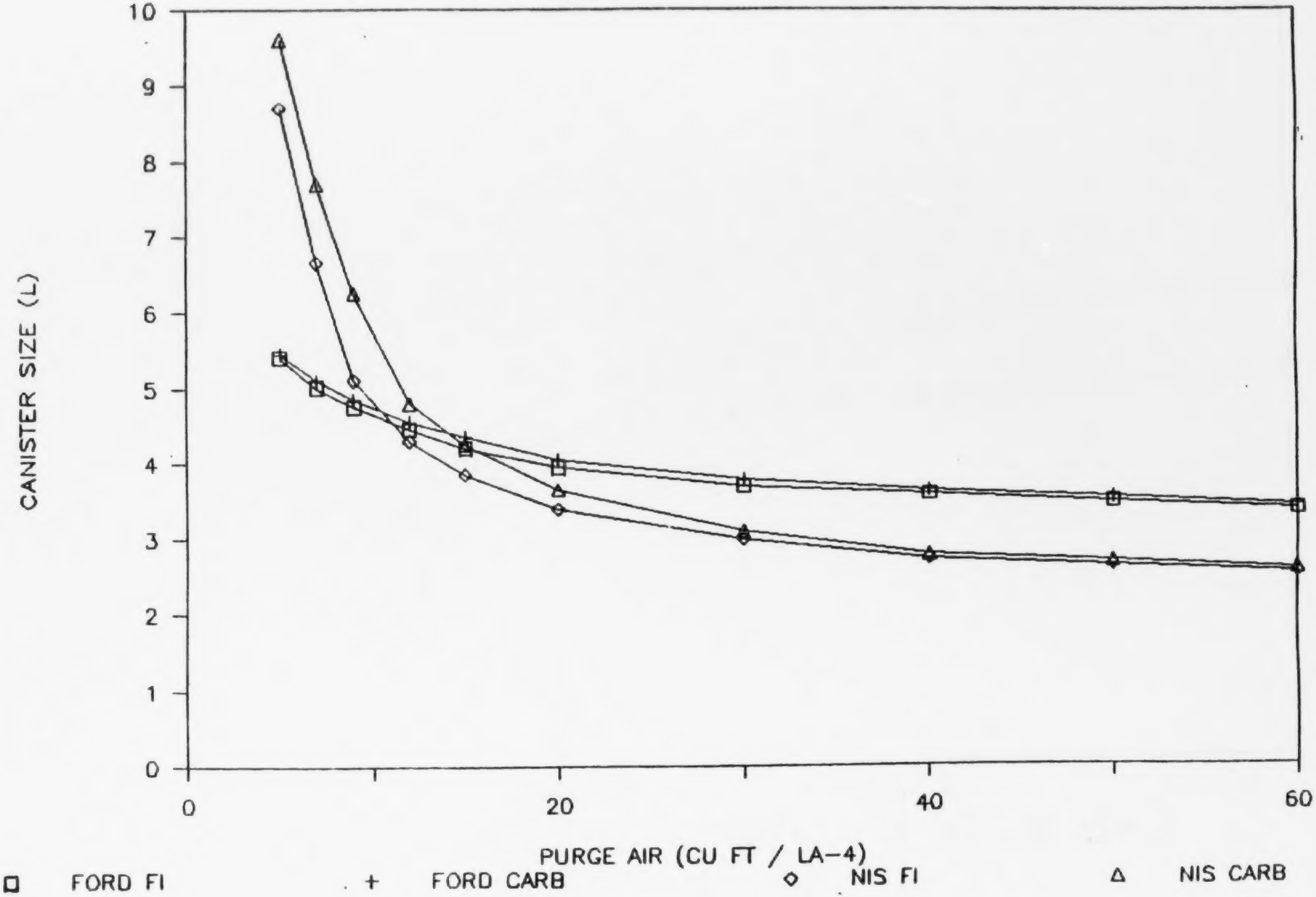
SMALL CAR FIGURE 10



CANISTER SIZE VS PURGE AIR FLOW RATE

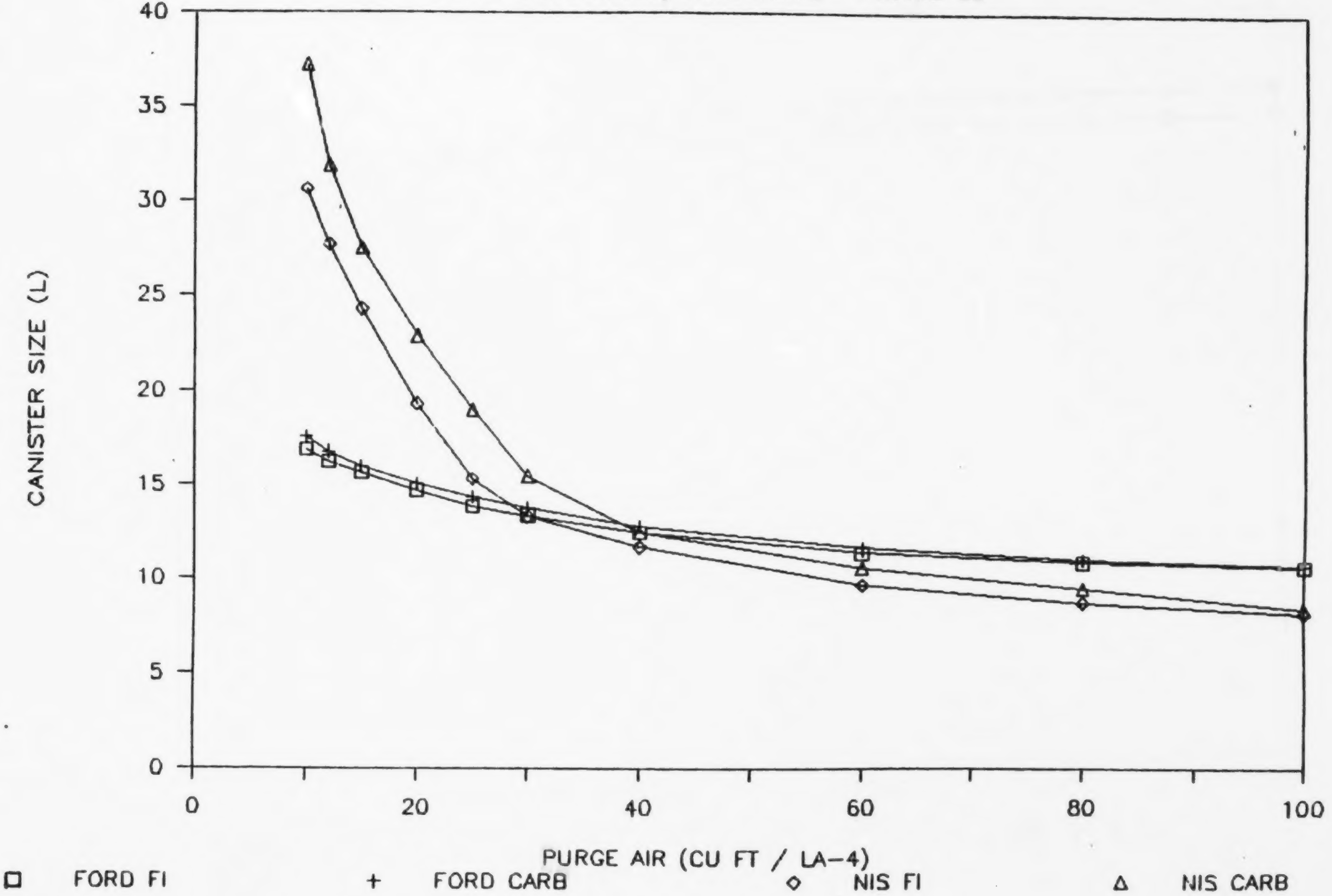
AVERAGE CAR

FIGURE 11



CANISTER SIZE VS PURGE AIR FLOW RATE

LIGHT DUTY TRUCK/DUAL TANKS FIGURE 12



CANISTER SIZE VS PURGE AIR FLOW RATE

HEAVY DUTY VEHICLE FIGURE 13

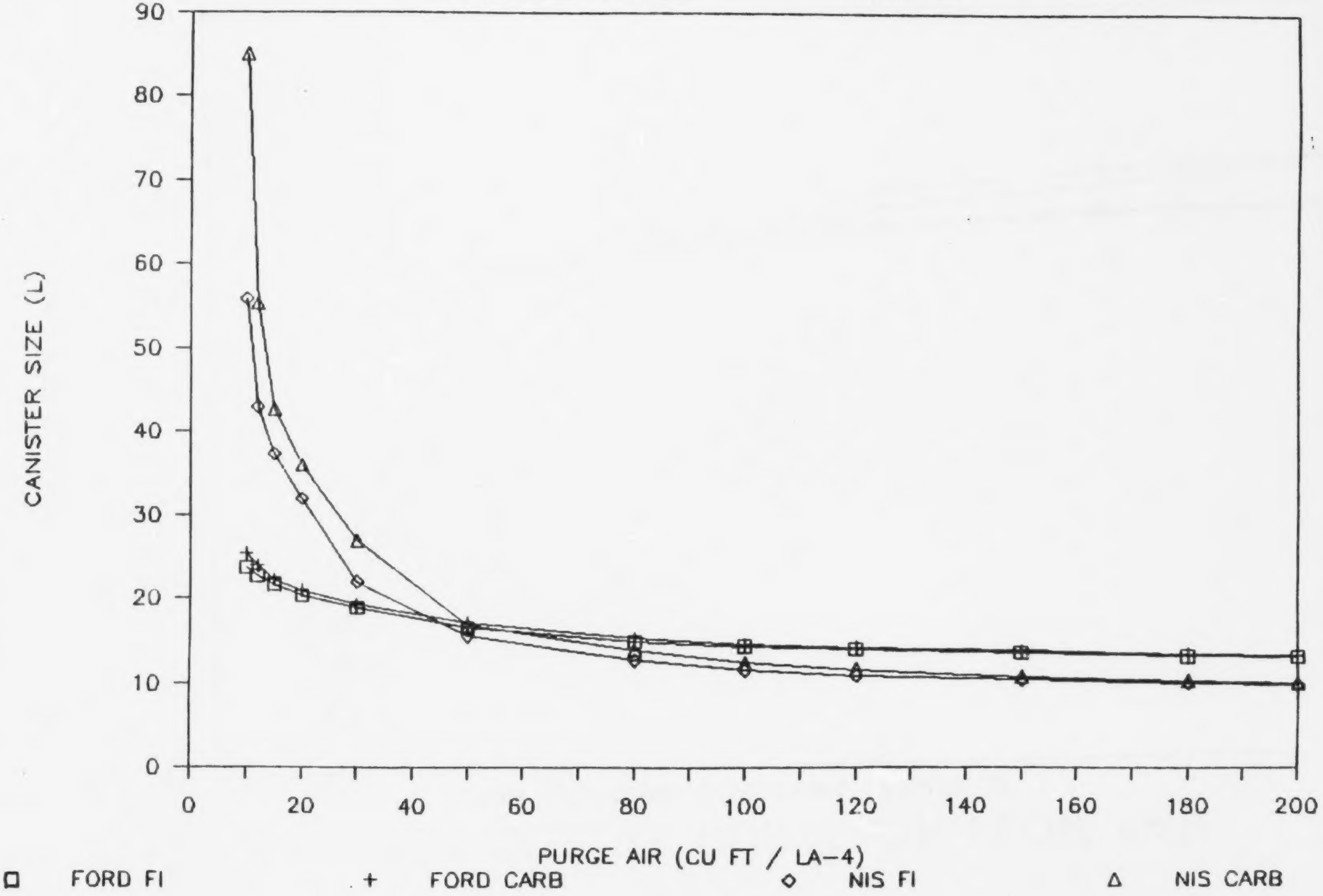


Table 3

Vehicle Parameters Used in Canister Sizing Calculations

Vehicle Type	Fuel Delivery System	Fuel Tank Volume (gal)	Hot Soak Loading (g)	Diurnal Loading (g)	Required Refueling Capacity (g)*
Small Car	Fuel Injection	8.2	6	14	65
Small Car	Carburetion	8.2	9	14	65
Average Car	Fuel Injection	13.0	10	22	104
Average Car	Carburetion	13.0	15	22	104
LDT (Dual tanks)	Fuel Injection	38.0	29	64	303
LDT (Dual tanks)	Carburetion	38.0	43	64	303
HDV	Fuel Injection	50.0	38	84	399
HDV	Carburetion	50.0	57	84	399

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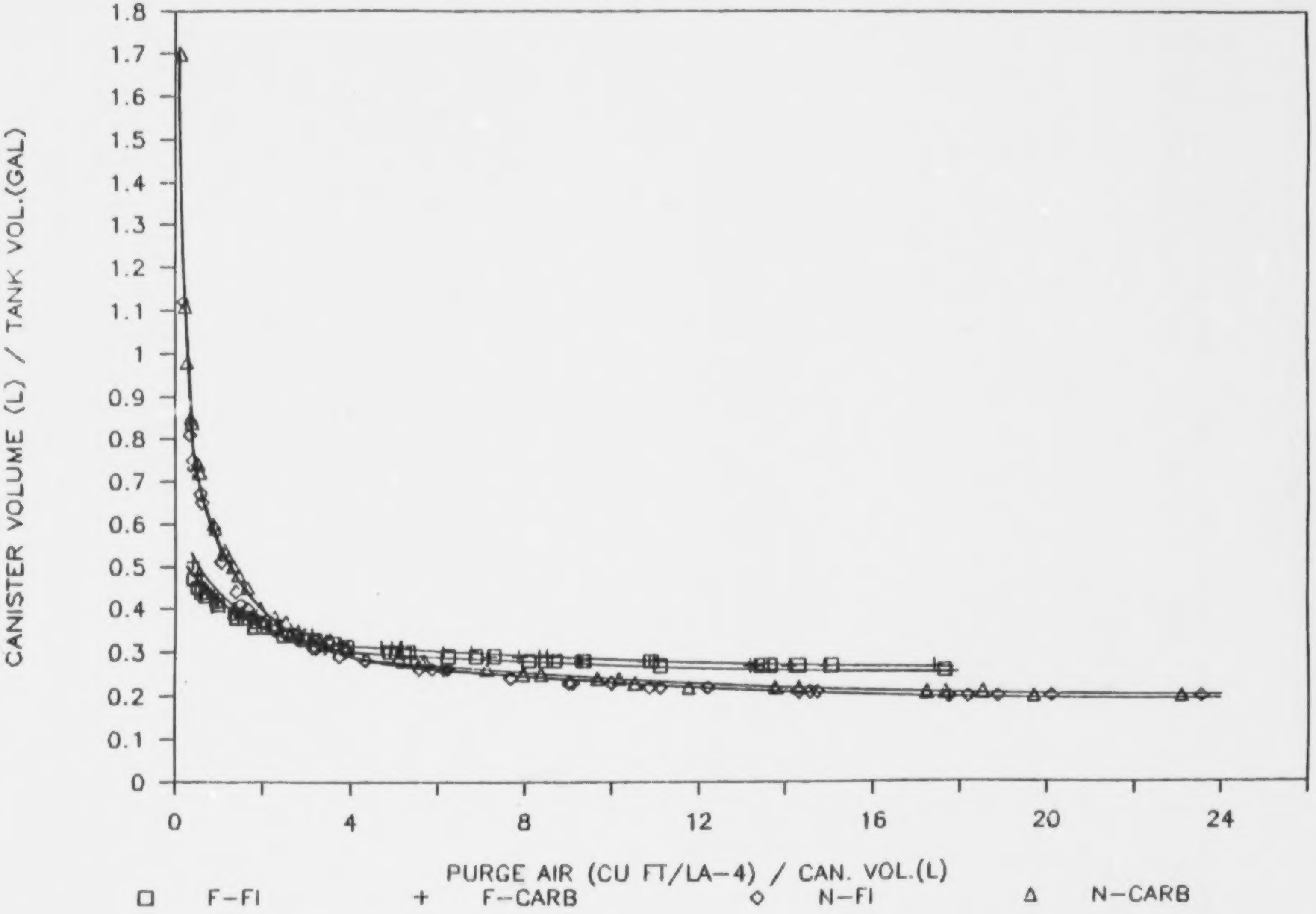
* Refueling capacity required calculated from refueling emissions at test conditions (i.e. 7.15 gram/gallon) x 85 percent of tank volume x 1.2 (to account for 20 percent entertainment with liquid seal) x 1.1 (to provide a 10 percent safety margin).

CANISTER SIZE VS. PURGE AIR FLOW RATE

NORMALIZED VALUES FIGURE 14



5.1 Basic Considerations

Control of the power output from a gasoline engine is accomplished by limiting the amount of air available to the engine, by means of a throttle placed in the engine intake system. The fuel metering system is designed to provide fuel in proportion to the amount of air allowed to enter the engine. Throttling of the intake air supply causes a reduction in the pressure of the air (or air and fuel mixture) in the intake manifold downstream of the throttle. This reduced pressure in the intake manifold downstream of the throttle provides an essentially zero cost method for moving the air necessary for purging of stored hydrocarbons from a canister. Activation of the canister purge system however, provides an additional source of air and fuel to the engine. This air is not under the control of the driver of the vehicle and the HC vapor (fuel) entrained in the air is not under the control of the engine's fuel metering system. Purging of the hydrocarbons stored in a canister can, therefore, impact engine operation through perturbations in the amount of air available to the engine and in the ratio of fuel to air supplied to the engine.

The purpose of this segment of the analysis is to develop an understanding of limits which may be applicable to canister purge air flow and to the fuel supplied by the canister if unacceptable negative impacts on engine operation are to be avoided. A stepwise presentation of the effects of activating the canister purge system will facilitate the desired analysis.

5.2 Purge Air

As was stated previously, activation of the canister purge system will allow more air and a variable amount of additional fuel to reach the engine. The resulting effect on engine operation will depend on the range of control and rate of response of the engine's fuel metering system. If the range of control were to be exceeded, the anticipated result could be either a substantial loss in power or stalling of the engine. Power loss would be associated either with an extremely rich or lean but ignitable mixture. Stalling would be associated with either a richening or leaning of the mixture beyond the ignition limit.

If the range of control was not exceeded, the effects on engine operation would depend on the speed with which the fuel metering system could compensate for the perturbation caused by the air and fuel coming from the canister. If the response rate was very rapid the effect would be for a rapid increase in the engine's power output because both the air and the fuel available to the engine increased and increased approximately in the correct relative ratio. As perceived by the driver, the effect would be for the vehicle to accelerate without a driver initiated action for acceleration. If the acceleration was small, it could go unnoticed by the driver. If, however, the acceleration was large, the driver could perceive the acceleration as a loss of control of the vehicle.

One straightforward approach to a large induced purge change is to simply use a damper or slowly operating purge control valve. Such a valve, by introducing the change in air flow over a lengthened period, would allow for driver compensation as a part of the normal driving process. In this way, a fairly large change could be made with no perceptible impact. Even so, it is worth evaluating reasonable limits for the purge perturbation to determine if such a control strategy is even needed.

On the assumption, then, that the vehicle could rapidly adjust to the sudden onset of purge, one limit for purge rate would be the maximum acceptable power perturbation it would produce. The size of this limit is estimated below (limits from the purge related fuel flow will be treated later).

Since vehicles presently do not incorporate systems which could cause relatively large, non-driver induced, changes in the power level at which the engine is operating and consequent vehicle accelerations or decelerations, it was necessary that a surrogate be identified. Vehicle accelerations and decelerations associated with the disengagement and engagement of air-conditioning compressors were selected as a guide to driver acceptable performance perturbations attributable to power changes at the driving wheels. This information was used in estimating a driver acceptable limit for purge air induced increases in engine power.

Figure 15 shows manufacturer supplied nominal values for the power required to drive air conditioning compressors on typical vehicles (values furnished by Honda are for city type operations and are, therefore, not expressed in terms of vehicle speed). Figures 16, 17, and 18 show nominal engine brake horsepower (BHP)* curves with and without air-conditioner

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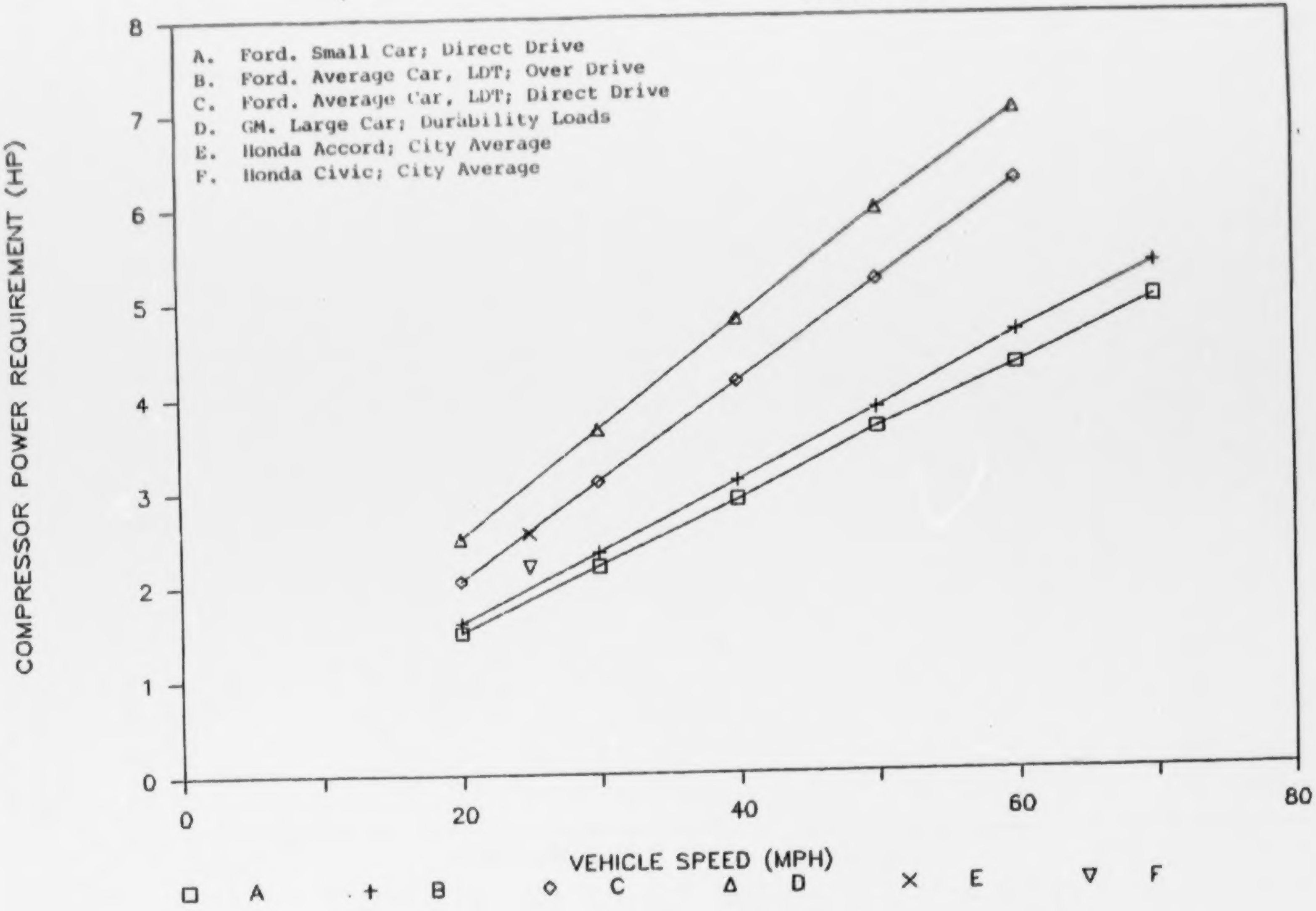
* Engine brake horsepower (useful external power) values were derived from typical chassis dynamometer power absorption curves with allowances for power losses at the tire to dyno interface, times allowances for drive axle and transmission efficiency plus allowances for the power requirements of the alternator, water pump, fan, air pump and power steering pump.

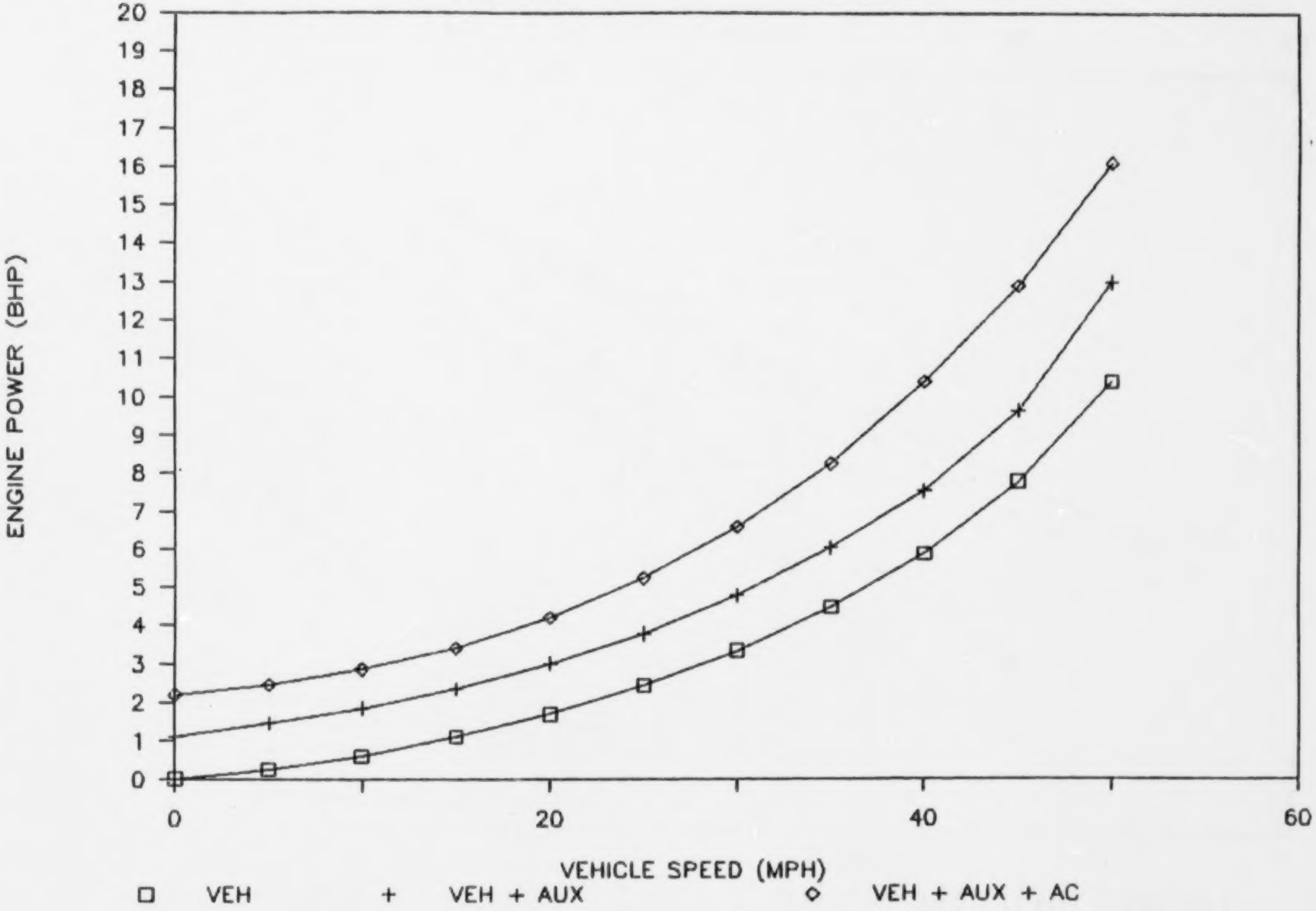
AIR COND COMPRESSOR POWER REQUIREMENT

FIGURE 15



ENGINE BHP VS VEHICLE SPEED

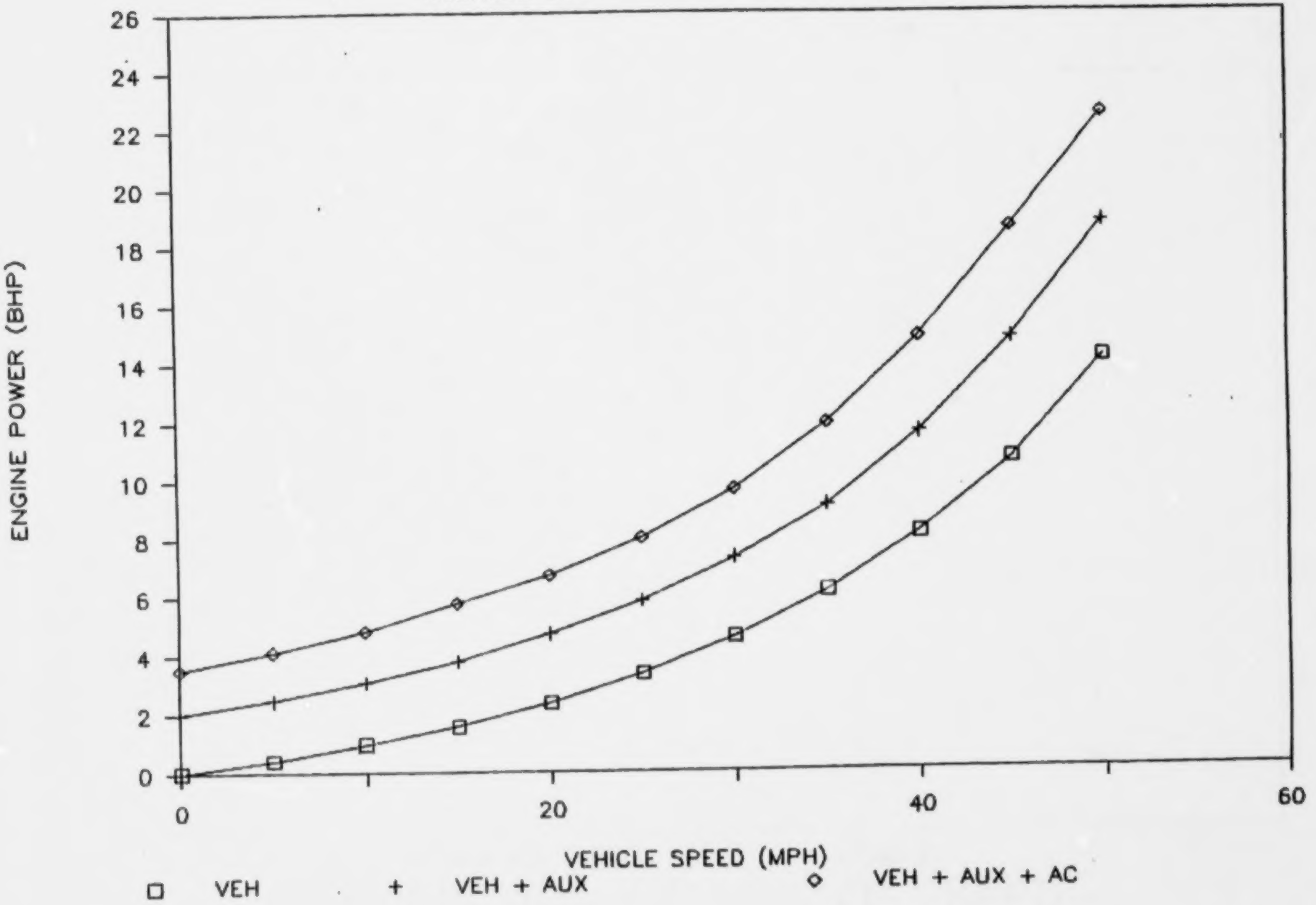
SMALL CAR FIGURE 16



ENGINE BHP VS VEHICLE SPEED

AVERAGE CAR

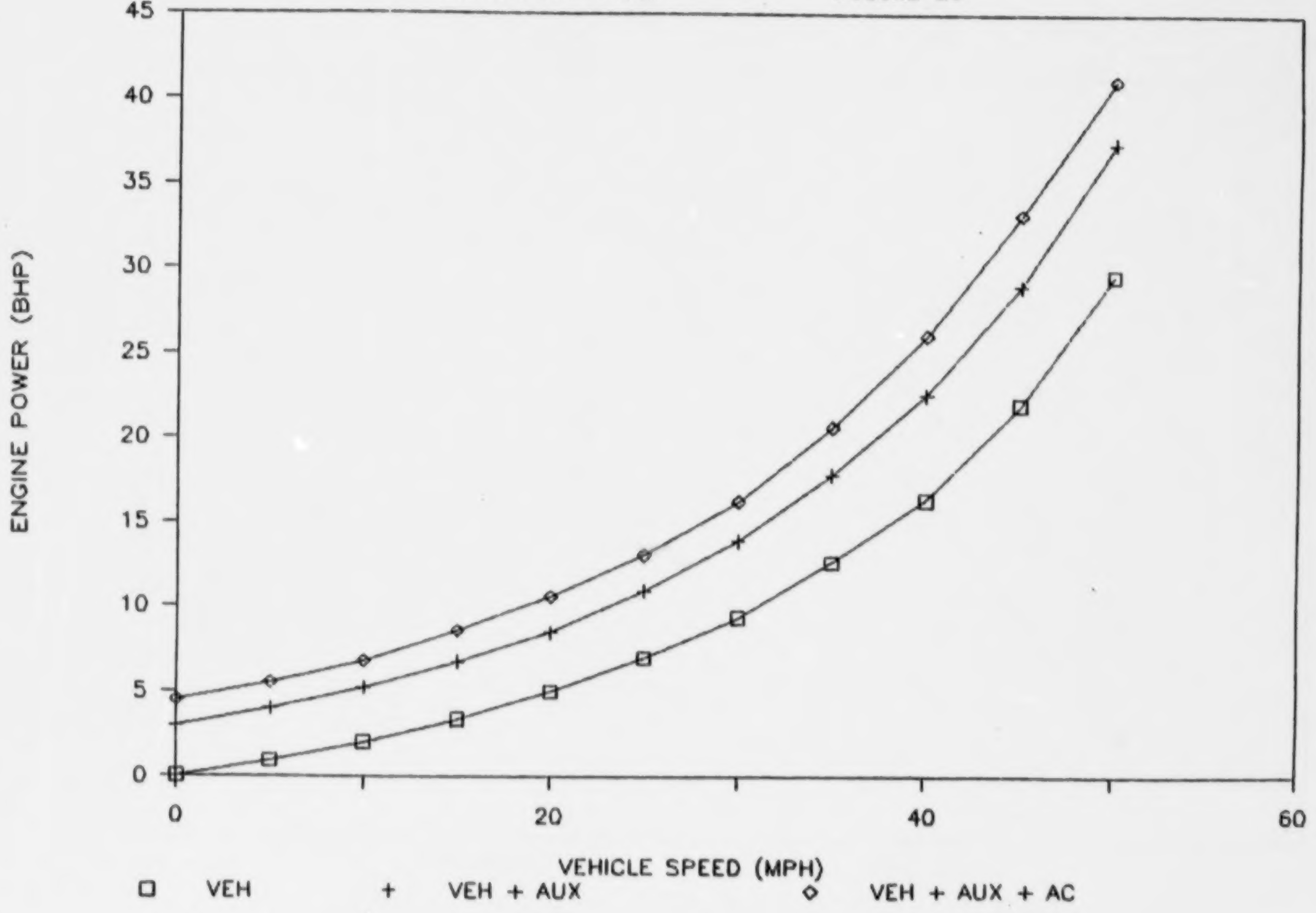
FIGURE 17



ENGINE BHP VS VEHICLE SPEED

LIGHT DUTY TRUCK

FIGURE 18



compressor loading for three sizes of vehicles (small car, average car and full-size light-duty truck). At any selected vehicle speed, the difference between the with and without air-conditioning compressor curves represents the incremental change in engine horsepower available to accelerate the vehicle when the compressor disengages. Incremental increases in engine power available to propel the vehicle when the air conditioning compressor turns off were extracted from Figures 14, 15 and 16 at 20, 35 and 50 mph and are shown in Table 4 as percentages of the BHP required to operate the vehicle.

The power consumption figures in Table 4 cannot be used directly to evaluate purge rates, because they are applicable to output power, while any purge perturbation will impact total engine power. Total, or indicated, power includes both output (brake) power and internal motoring power. However, at the relatively low output (brake) power levels involved in the data being used here, it appears reasonable to assume that losses within the engine could approximate the brake horsepower output. Using this approximation, the percentage change in total engine power for an average car when the compressor cycles off at 35 mph would be approximately one half of the 31 percent change in brake power shown in Table 4, or about 15 percent. Similarly, average percentage changes in total engine power for the three vehicle types are about 8, 15 and 17 percent for LDTs, average cars and small cars respectively. For the two car sizes only, the average change is about 16 percent and this value was selected as a representative upper limit for the impact of an increase in air flow attributable to canister purging. Since the incremental increase in total engine power is directly proportional to the incremental increase in air flow, the 16 percent value can be applied directly to the purge air flow rate.

Conversion of the 16 percent of engine air flow value to a volume of air purged through the canister was derived from fuel economy values for the vehicles on the LA-4 employing the assumption that stoichiometic air/fuel ratio would be maintained throughout. The fuel economy values employed for a small car, an average car and a full-size LDT were 52, 25 and 14.5 mpg respectively. A value of 7.5 mpg was assigned for a heavy-duty gasoline vehicle. The corresponding volumes of air used by the vehicles on an LA-4 are 178, 369 and 637 and 1231 ft^3. The canister purge air flow rates corresponding to 16 percent of the engine total air consumption so calculated are 28, 59, 102 and 197 ft^3 of air per LA-4 for a small car, an average car, a full-size light duty truck and a heavy-duty gasoline vehicle respectively. These values, rounded to 30, 60, 100 and 200 ft^3 of air per LA-4 were used as initial estimates of upper limits for canister purge air volumes for systems characterized by the sudden onset of purge flow.

Table 4

Air Conditioner Compressor Power Requirements Expressed As Percentages of Power Required To Power The Vehicle At Three Speeds

Vehicle Speed	Air Conditioner Compressor Power as Percent of Vehicle Motive Power		
	Small Car	Average Car	Light Duty Truck
20	43	40	24
35	36	31	16
50	25	20	10

Referring back to Figures 10, 11, 12 and 13, these values can be seen to approximately correspond to the maximum purge rates evaluated. They occur in the region of the curves where there is little sensitivity of canister size to purge rate. They, therefore, do not appear to represent any serious constraint on system design or the tradeoff between purge rate and canister size. However, as noted at the onset, if it were desirable to operate at higher purge rates than these limits, the power perturbation should not present a serious limiting factor because of the ability to use such techniques as damped purge control valves.

5.3 Canister Supplied Fuel

To this point, the analysis has looked at only one of the two canister purge factors which can impact engine operation (i.e., the amount of air coming from the canister). The second factor, canister supplied hydrocarbons which become part of the total volume of fuel supplied to the engine, is evaluated here. This analysis is performed by first examining existing evaporative systems, followed by an extrapolation to onboard systems.

5.3.1 Present Evaporative Control Systems

Purging of hydrocarbons stored in evaporative emission canisters is presently being performed without an excessively negative effect on engine operation. Test data reported by API (Test Protocol for Automotive Evaporative Emissions, API Publication No. 4393) shows a range for evaporative canister purge air rates from a low of approximately 3 ft^3 per LA-4 up to approximately 11 ft^3 per LA-4 for the six GM and Ford vehicles tested. Combining the purge rates for each vehicle with the purge curve for Ford type canisters provides an estimate of the maximum mass of hydrocarbon purged from a fully loaded evaporative canister during an LA-4 (the Ford type canister characteristic was selected because it exhibits the highest initial desorption rates). For the six vehicles tested by API, the measured volume of air purged per LA-4 and the estimated mass of hydrocarbon purged from the canister, starting with a loaded canister, is shown in Table 5.

Using the fuel economy values measured for each vehicle and the assumption used previously that the air/fuel ratio is maintained at 14.7:1, the mass of fuel and volume of air consumed by each vehicle during an LA-4 were calculated. The measured volumes of air coming from the canister and the estimated maximum mass of hydrocarbon purged from the canister during an LA-4 were then expressed as percentages of air and fuel used. These values are shown in Table 6.

Table 5

Evaporative Canister Purge Rates and Corresponding HC Removal for Six Production Vehicles

Test Vehicle	Measured Fuel Economy on the LA-4 (mpg)	Measured Canister Purge Air per LA-4 (ft^3)	Estimated Maximum HC Purged per LA-4 (g)*
1983 Malibu (carb)	17.5	8.5	27.0
1983 Escort (carb)	24.1	6.5	25.5
1981 Omega (carb)	21.8	11.0	28.0
1983 Fairmont (carb)	17.3	7.5	26.5
1984 Omega (FI)	23.4	3.0	21.5
1984 Escort (FI)	27.0	10.0	27.8

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* Because the HC purge of a canister is very high when the canister is fully loaded and decreases as the canister loading decreases, maximum HC purged during a LA-4 drive occurs when the drive is initiated with a fully loaded canister. Depending on the level of HC stored in the canister at the start of an LA-4 drive, the HC purged would vary from this maximum down to almost zero for a drive which was initiated with a nearly empty canister.

Table 6

Air and Fuel Coming From Evaporative Canister During an LA-4 for Six Production Vehicles

Vehicle	Total Fuel used per LA-4 (g)*	Total Air used per LA-4 (ft^3)**	Percent*** of Total Fuel From Canister per LA-4	Percent Total Air From Canister per LA-4
1983 Malibu	1217	528	2.2	1.6
1983 Escort	884	384	2.9	1.7
1981 Omega	997	424	2.9	2.6
1983 Fairmont	1231	535	5.0	1.4
1984 Omega	910	395	5.4	0.8
1984 Escort	789	343	3.5	2.9

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* Fuel used in grams = (7.5 miles) E (MPG) x (3785.4 cc/gal) x (0.75 g/cc gasoline).

** Total air used in ft^3 = (grams fuel used) x (14.7) x (1/453.6 g/lb) x 13.4 ft^3/lb.

*** Assuming LA-4 operation starts with a canister loaded to breakthrough.

Because of the non-linear shape of the canister purge curve, the average percentage of total fuel supplied from the evaporative canister over an LA-4 does not represent the greatest percentage of fuel contributed by the canister. The largest fuel contribution occurs just after canister purging is initiated i.e., during the first mile or fraction of a mile following initiation of purging. To investigate the maximum* percentage of fuel contributed by the evaporative canister on current vehicles, the computer model was used to calculate the percentage of total fuel coming from the canister for each of the first five miles of LA-4 operation, based upon the average fuel consumption of the vehicle. The results from this analysis are shown in Table 7 for each of the six vehicles analyzed.

As can be seen in Table 7 the percentage of total engine fuel supplied by the evaporative canisters starts at highs of between 6 and 16 percent for the first mile of vehicle operation and diminishes as the canister purges. The percent of fuel coming from the canister would reach zero when the canister is fully purged. The values of 6 to 16 percent of total engine fuel supplied by the evaporative canister can be used as representative values for fuel supplied by a canister which do not presently produce adverse effects on engine performance.

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* Because of the transient speed characteristic of the LA-4 and, therefore, transient engine loading and corresponding transient air and fuel flow to the engine, the term maximum here means the maximum averaged over a part of the LA-4 and not a maximum which may occur during short term transients. A transient maximum would tend to occur when the air and fuel flow rates from the canister were high and the engine was working at a light load, e.g., in the transition period from a cruise to a deceleration but prior to a reduction in canister supplied air and fuel. Actual determination of such a maximum would require continuous measurements of both air and fuel flows from the canister and through the engine's primary air and fuel supply systems. For this analysis the use of mile by mile maximum values on the LA-4 are considered to be acceptably accurate values for comparisons between present evaporative control systems and onboard systems because the onboard systems are projected to operate relatively similarly to present evaporative systems.

Table 7

Percent Total Engine Fuel Coming From Evaporative Canisters During the First Five Miles of Purging

Vehicle	Percent Total Fuel Purged from Canister for each of the first five miles of the LA-4				
	1st Mile	2nd Mile	3rd Mile	4th Mile	5th Mile
1983 Malibu	10	3	1	1	1
1983 Escort	12	4	2	1	1
1981 Omega	14	3	2	1	1
1983 Fairmont	9	3	1	1	1
1984 Omega	6	4	3	2	1
1984 Escort	16	3	2	1	1

5.3.2 Onboard Control Canisters

Having identified the first mile fuel contributions from current evaporative emission canisters, the previously sized onboard refueling canisters were similarly reanalyzed to determine their first mile fuel contributions. The results from this reanalysis are shown in Figures 19 through 22 as percent first mile fuel from the canister plotted against percent engine air coming from the canister. The largest values for percent first mile fuel (16 percent, Table 7) and percent air (2.9 percent, Table 6) from the canister for the vehicles reported in the API study are also shown to indicate present practice.

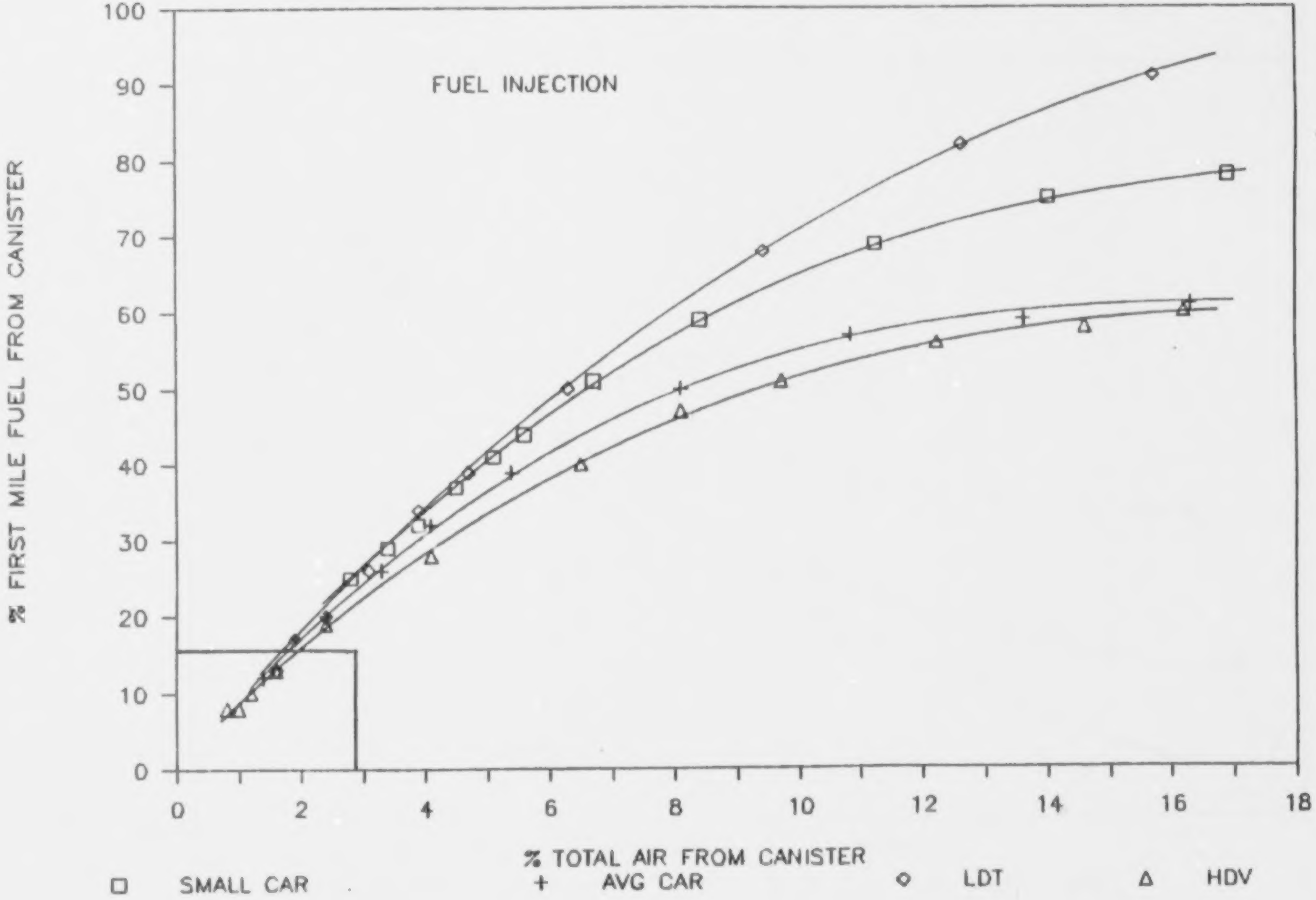
As can be seen in Figures 19 through 22, first mile fuel contributions by onboard canisters at higher purge rates can substantially exceed current evaporative canister first mile fuel contributions. While there is presently no data to indicate the degree to which first mile fuel contributions could increase beyond present evaporative canister practice, it appears reasonable to assume that the largest values shown (e.g., 80 to 90 percent of engine full) could cause operational problems. Therefore, canister supplied fuel appears to be a bigger constraint than does purge air flow.

Reproduced in Figures 23 through 26 are the canister size versus purge air flow rate tradeoff curves for fuel injected systems as previously presented as Figures 10 through 13, with information added to indicate the points on these curves corresponding to various percent first mile fuel values. Indicated are values of 15 percent (approximately current evaporative system practice), 25 percent and 35 percent. As can be seen from these figures, a first mile fuel constraint would limit the use of the smallest canister highest purge air flow systems. The actual impact of this constraint would depend on the degree to which the vehicle's fuel metering system could accommodate fuel supplied due to canister purging.

One possible strategy for dealing with this matter comes from the basic canister purge characteristics. Referring back to Table 7, it can be seen that the percent of the engine fuel coming from the evaporative canister falls off quite rapidly after the first mile of operation. This trend is similar for onboard systems (see Table 8). Thus, by modulation of the purge air flow rate to reduce the flow rate initially and increase it later in the trip the first mile fuel could be reduced and spread out more gradually over subsequent miles.

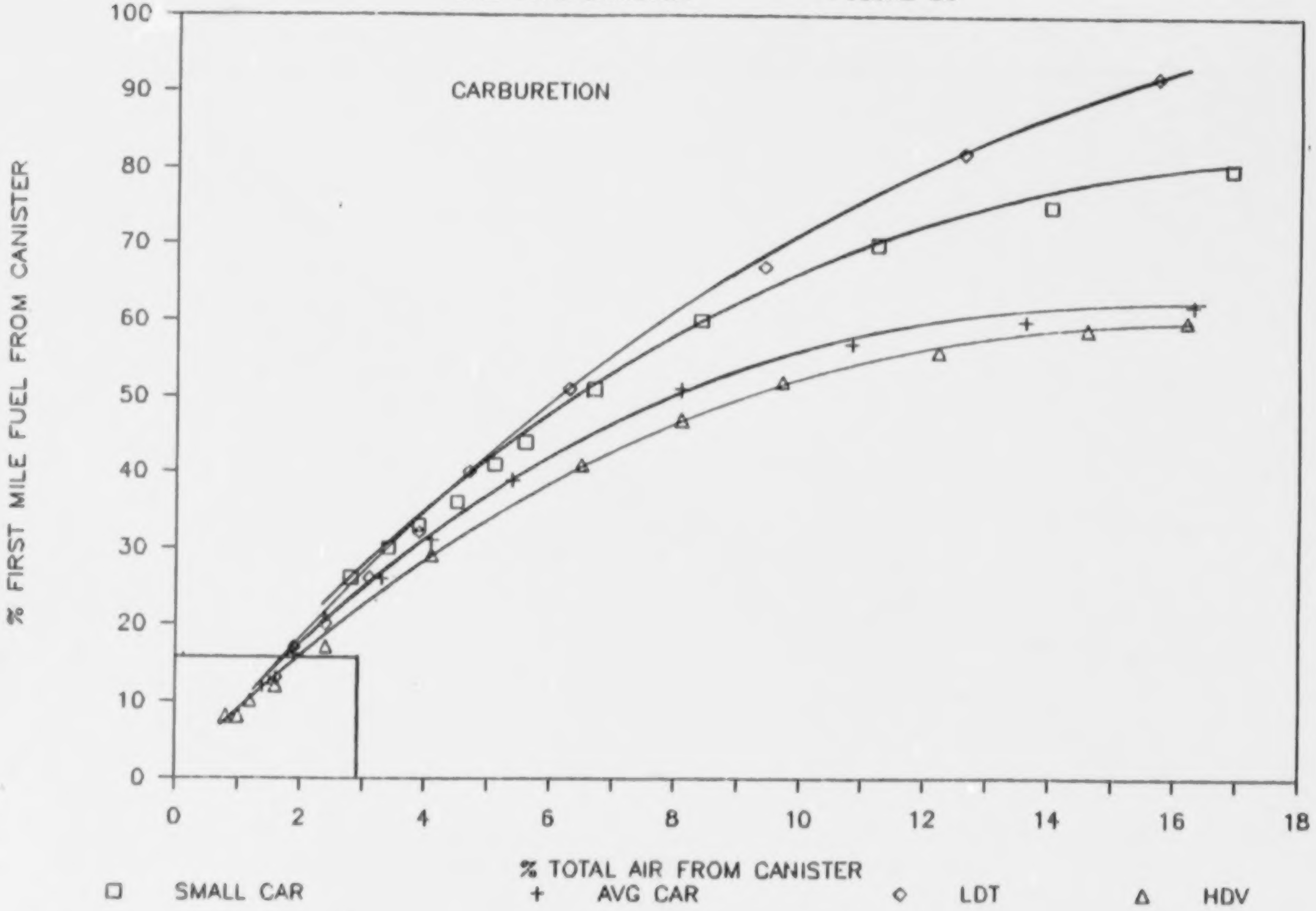
% FIRST MILE FUEL VS % TOTAL AIR

FORD TYPE CANISTER FIGURE 19



% FIRST MILE FUEL VS % TOTAL AIR

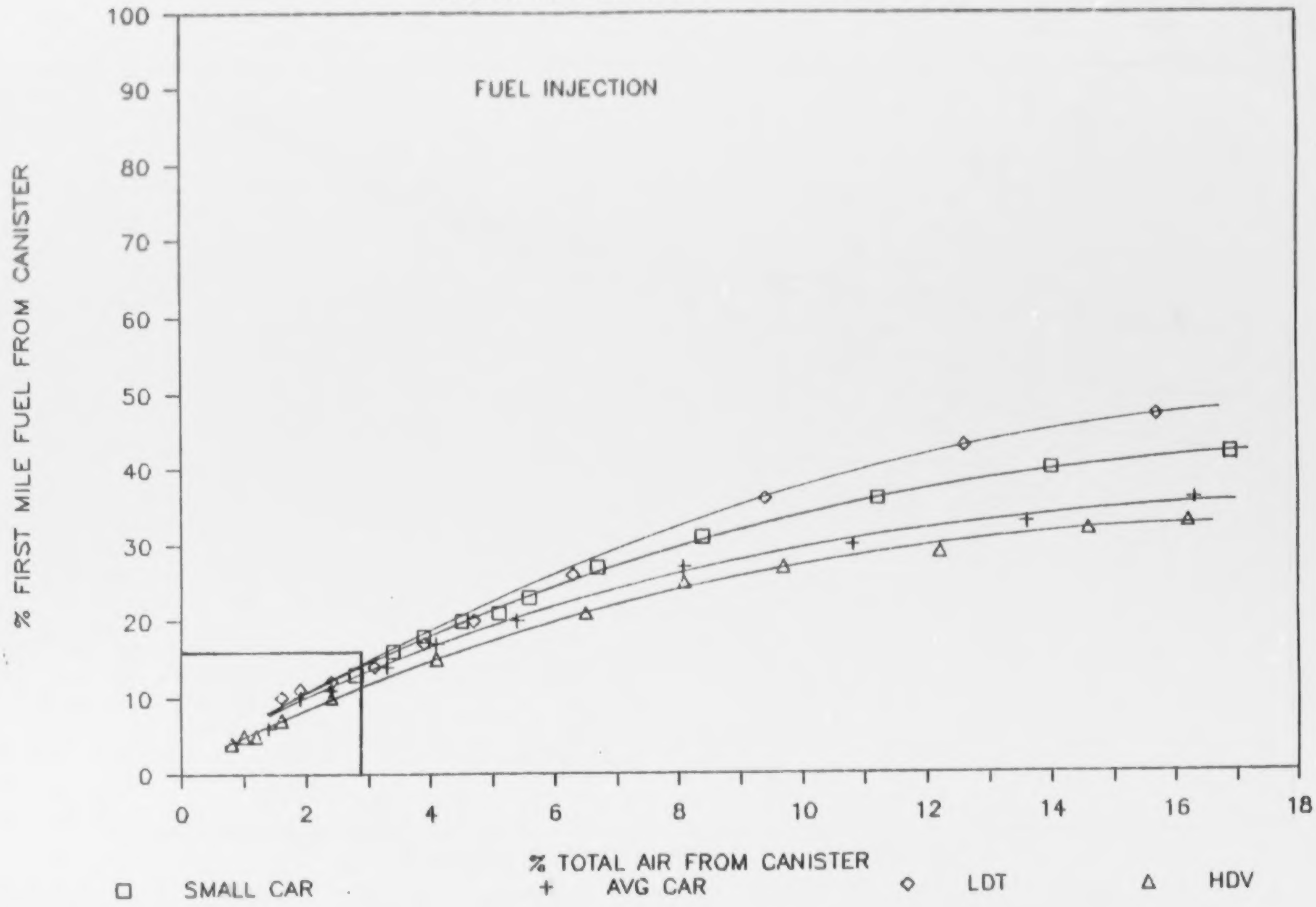
FORD TYPE CANISTER FIGURE 20



% FIRST MILE FUEL VS % TOTAL AIR

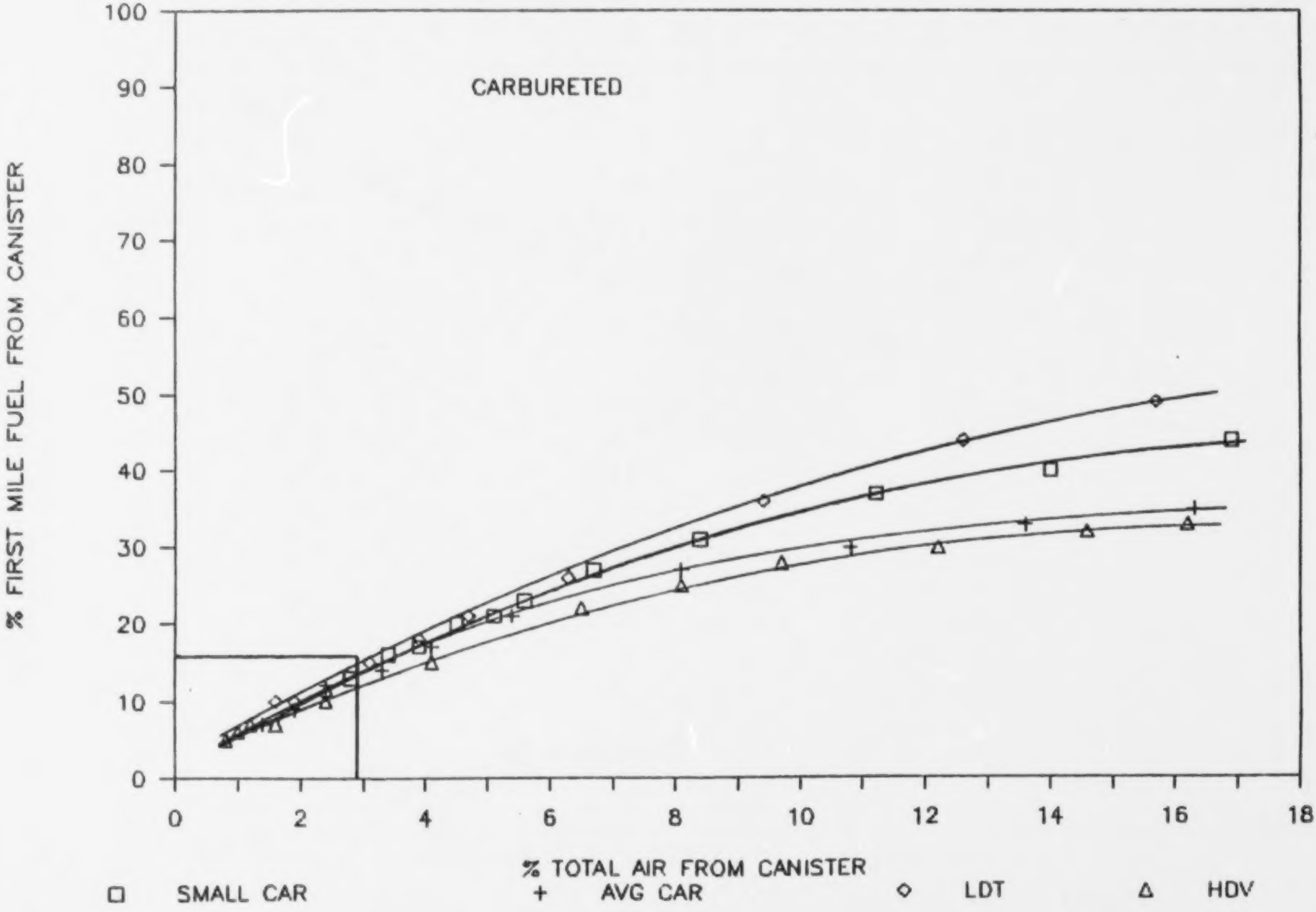
NISSAN TYPE CANISTER

FIGURE 21



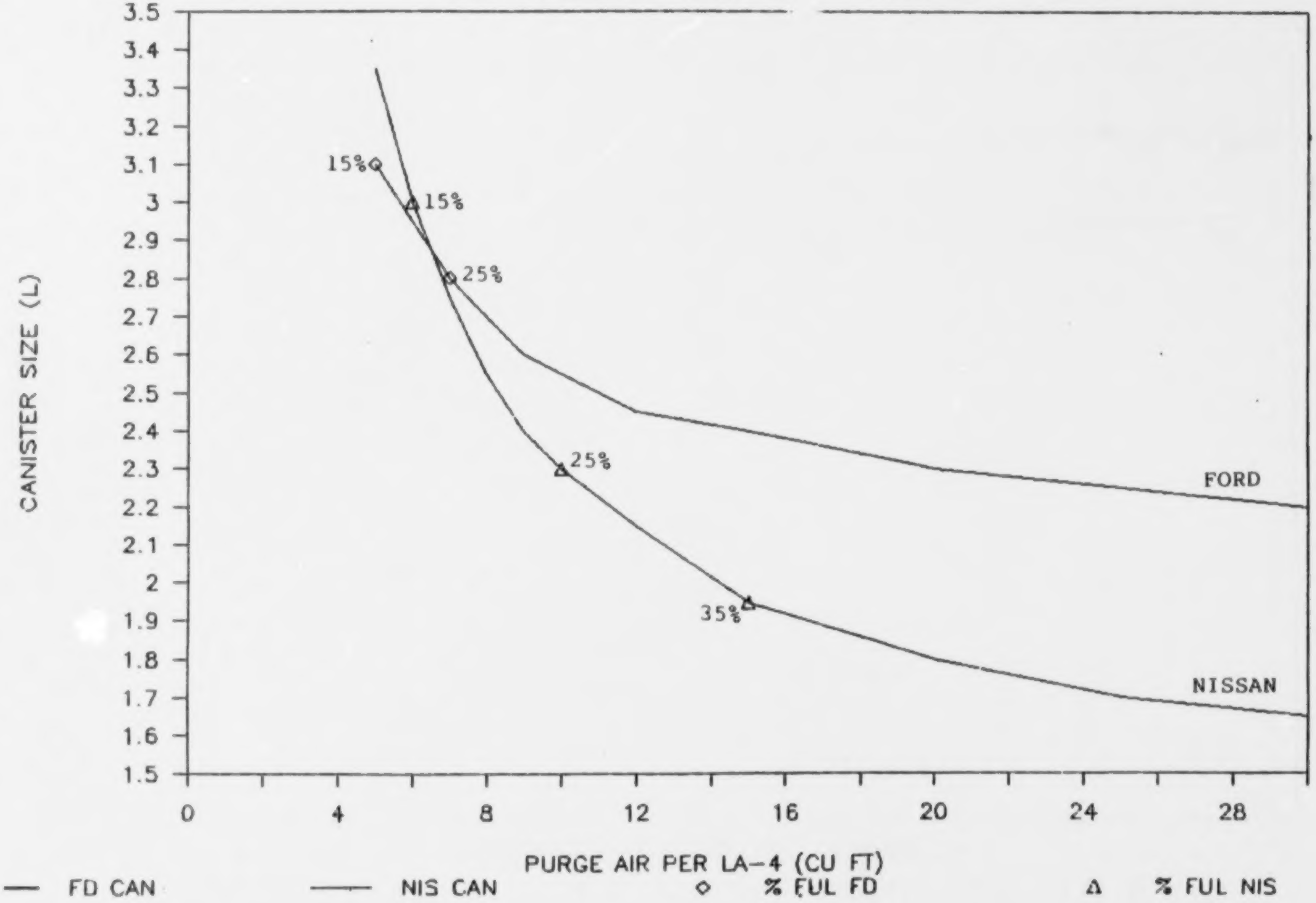
% FIRST MILE FUEL VS % TOTAL AIR

NISSAN TYPE CANISTER FIGURE 22



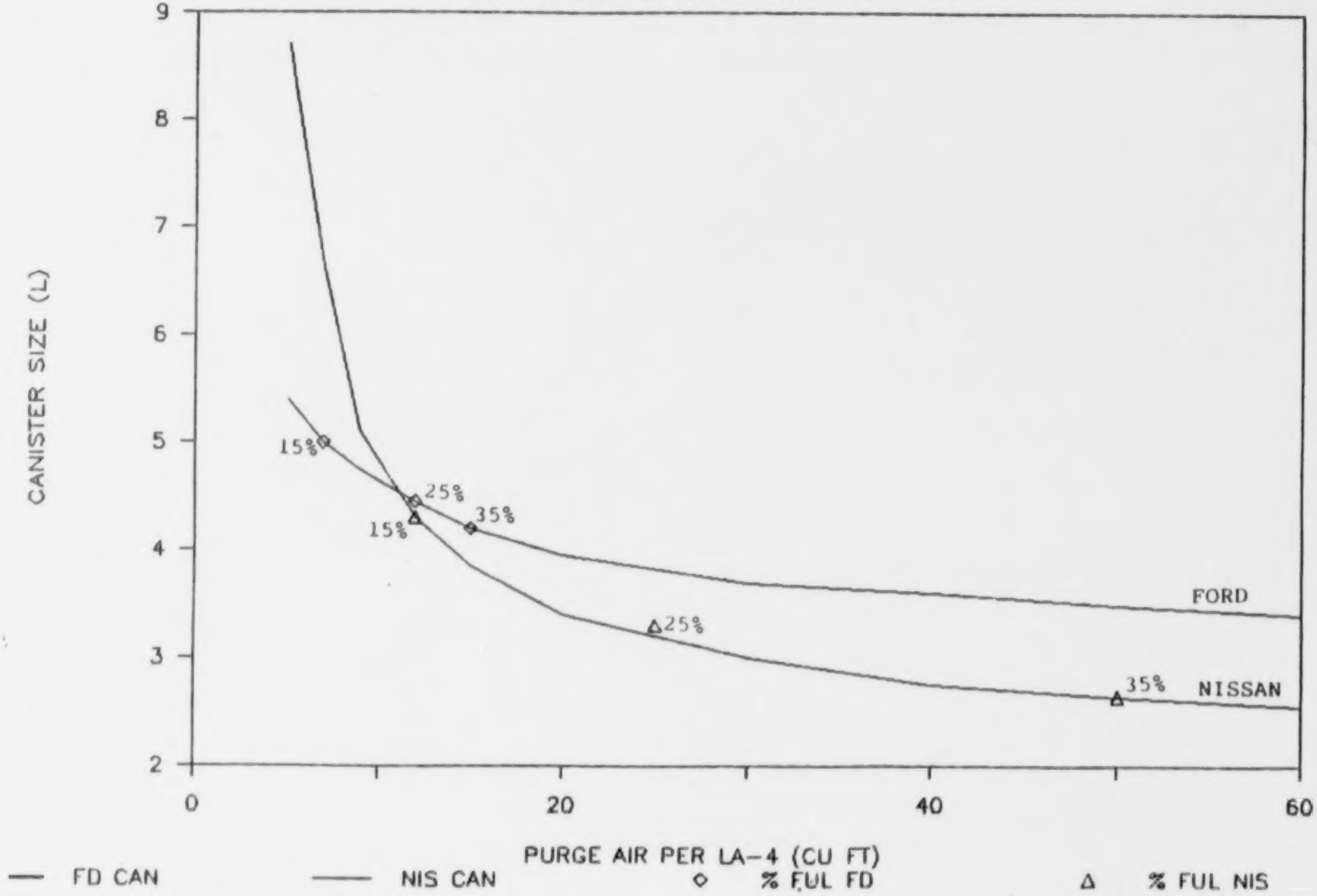
% FIRST MILE FUEL FROM CANISTER SM CAR

CANISTER SIZE VS PURGE AIR FIGURE 23



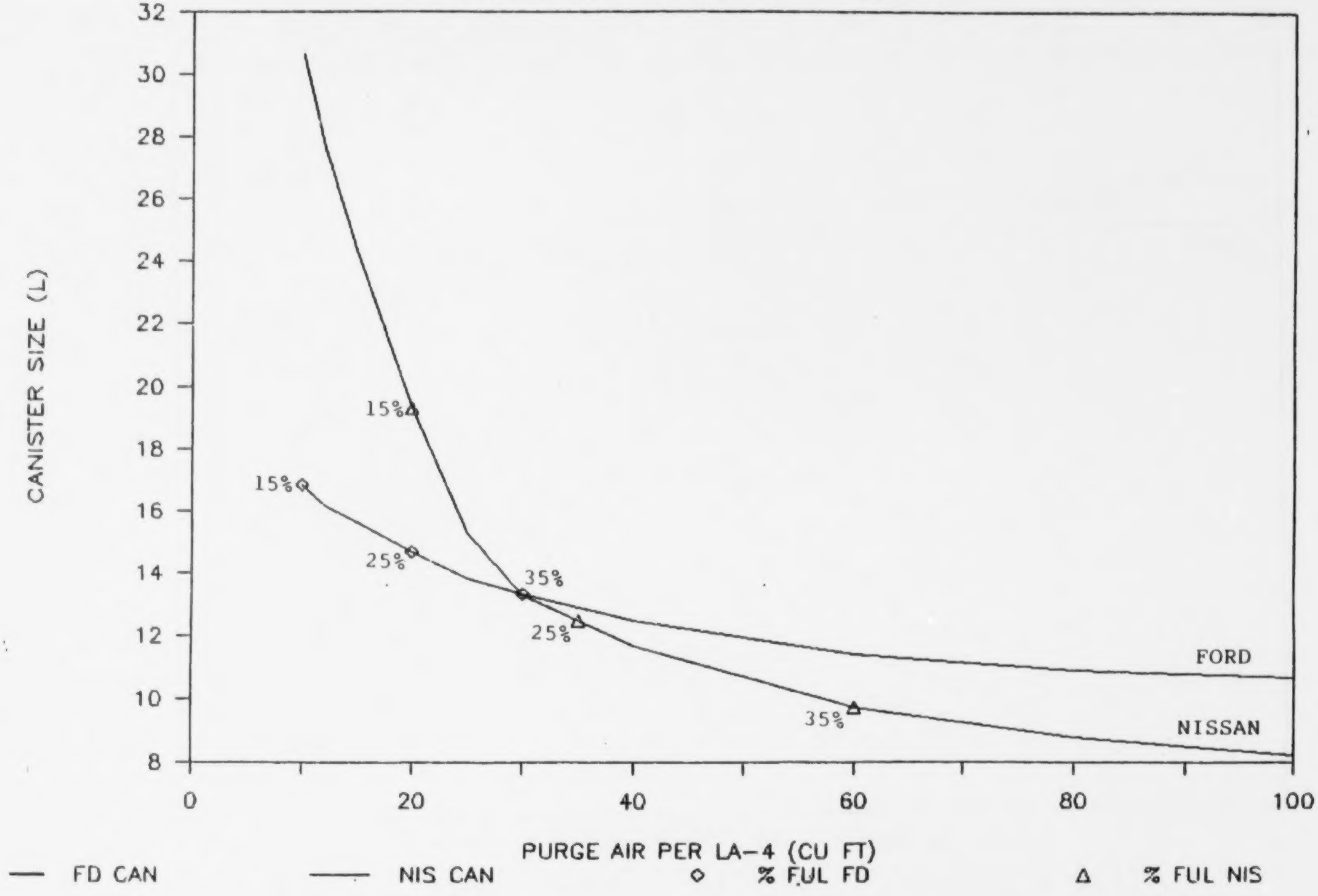
% FIRST MILE FUEL FROM CANISTER AV CAR

CANISTER SIZE VS PURGE AIR FIGURE 24



% FIRST MILE FUEL FROM CANISTER LDT

CANISTER SIZE VS PURGE AIR FIGURE 25



% FIRST MILE FUEL FROM CANISTER HDV

CANISTER SIZE VS PURGE AIR FIGURE 26

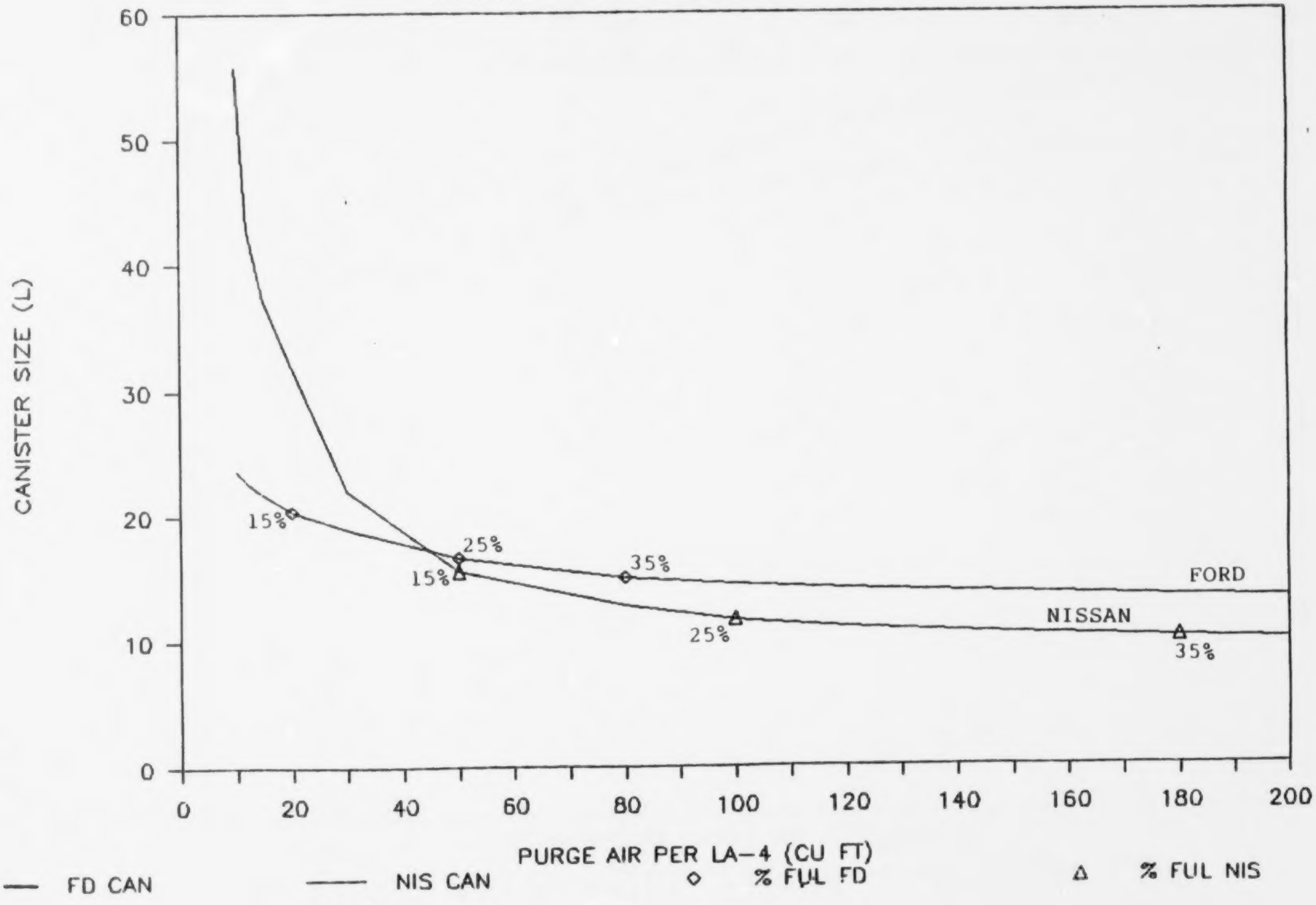


Table 8

Percent Total Engine Fuel Coming From Typical Onboard Canisters During the First Five Miles of Driving

	Percent Total Fuel Purged From Canister for Each of the First Five Miles of the LA-4				
Vehicle	1st Mile	2nd Mile	3rd Mile	4th Mile	5th Mile
Small Car (2.4l; 9 ft^3)N*	21	16	12	8	7
Small Car (2.65l; 9 ft^3)F	40	28	17	9	5
Average Car (3.0l; 30 ft^3)N	27	11	9	8	7
Average Car (4.6l; 10 ft^3)F	23	17	15	10	7
LDT (20l; 20 ft^3)N	14	13	12	11	10
LDT (15l; 20 ft^3)F	26	24	21	20	15
HDGV (52.5l; 50 ft^3)N	16	14	14	12	12
HDGV (32.3l; 50 ft^3)F	31	28	21	21	19

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* Size of canister in liters, purge air flow rate in ft^3/LA-4, N = Nissan type, F = Ford type.

6. Summary

Prior to proceeding with the section of the analysis which addresses test procedure revisions, it is appropriate to summarize the key findings of the analysis to this point as they relate to vehicle conditioning for refueling measurements. The analysis of canister and vehicle operational characteristics has shown:

- That the level of hydrocarbon stored in the canister when the vehicle is operated under repetitive cyclic drive, hot soak and diurnal conditions reaches stabilization after at most a few days of operation.
- That the canister stabilization level is highly dependent upon the operating pattern of the vehicle and on the amount of purge which occurs with each drive and the amount of loading which occurs with each hot soak and diurnal.
- That, for continuous driving with no hot soak or diurnal emissions, the canister will be rapidly purged to a very low level.
- That, for given hot soak and diurnal loadings, appropriate selection of canister size and purge air flow rate will provide adequate storage capacity for refueling vapors at the stabilized canister loading.
- That a range of canister size and purge air flow rate choices are available for any given vehicle which should not adversely affect vehicle performance.
- That while required canister size is inversely proportional to purge air flow rate, the relationship is not linear.

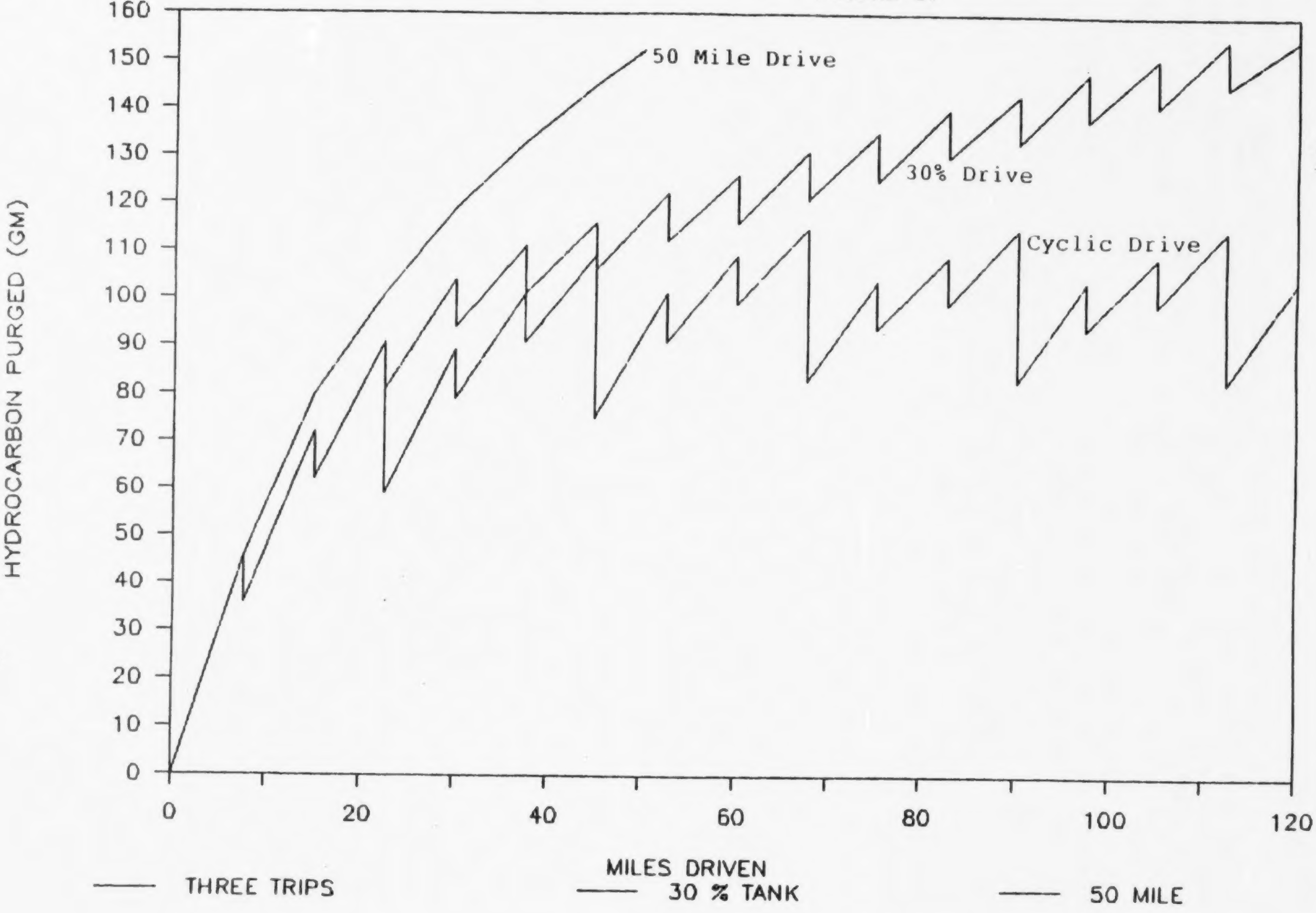
7. Test Procedure Revision

7.1 Evaluation of Preconditioning in Draft Procedure

The preceding analysis has identified how an onboard canister would be expected to purge and load during typical in-use operation and has provided a method for modeling this operation. A comparison of the effects on canister purging due either to the 50 mile continuous drive or the 30 percent drive-down steps proposed in the original draft procedure with a representative onboard canister performance curve is shown in Figure 27. As can be seen, both the 50 mile drive and the 30

CANISTER PURGE – THREE DRIVE TYPES

FIGURE 27



percent drive-down purge the canister well beyond expected in-use levels. These procedures would, therefore, produce non-representative canister purges and would not be appropriate for canister conditioning prior to the measurement of refueling emissions.

It is also apparent from the modeling work that canister purge and refueling capacity are not separable items, and that the approach used in the original draft procedure of evaluating each aspect with a separate test is inappropriate. The actual storage capacity which the vehicle will have available upon refueling is a function of the canister purge rate and the vehicle driving pattern as well as of the canister size. Because of this, the performance of the entire refueling system can be evaluated with a single test which first preconditions the canister to a level near its equilibrium level and then performs the refueling operation. This greatly reduces the overall complexity of the refueling test and its resource impacts and also allows it to be separated from the testing for exhaust and evaporative emissions. The following section develops the preconditioning procedures needed for the revised test.

7.2 Revised Canister Conditioning

Based upon the modeling which has been done, there are two options for simulating in-use performance. The first is a cyclic drive-down of alternating drives and soaks directly simulating a few "days" of vehicle operation to approximately establish the canister equilibrium level. The second is a short, continuous, drive-down to the equilibrium level with no soak periods.

Reproduction in the laboratory of the cyclic in-use daily operating pattern would be accomplished by the repetitive performance of a simulated daily pattern consisting of three LA-4s, each separated by a one hour hot soak plus the performance of a diurnal heat build following the last hot soak. This "daily" canister conditioning sequence would constitute the basic building block for the construction of the canister conditioning phase of the onboard test procedure. Sequential repetitions of this basic sequence until the canister stabilization level was reached (or approximated, in the case of a canister system requiring an unusually long time to completely stabilize) would constitute the primary procedure whereby canisters would be conditioned prior to measurement of refueling emissions.

There are several things to note about this approach. First, it should accurately simulate a realistic conditioning sequence. Of course, as noted in the earlier discussion of the effects of driving patterns, in-use patterns of less than three trips per day would purge less than would this procedure. However, there are compensating conditions of test condition stringency which act to offset this difficulty. Secondly, it appears that nearly all vehicles will reach equilibrium within three to five "days" of simulated operation. In fact, after only three "days", all vehicles appear to be within at most a few grams of equilibrium. Therefore, three simulated days should provide adequate canister conditioning. This, of course, means that conditioning can be performed with substantially fewer testing resources than the originally proposed 30 percent drive-down. Third, because of the rapid rate of purge when the canister is fully loaded, this conditioning sequence is relatively insensitive to the initial starting condition of the canister. The initial period of canister purging to a level near the equilibrium level occurs within the first dozen or so driving miles, so the total time to reach stabilization is not significantly affected by the initial loading on the canister.

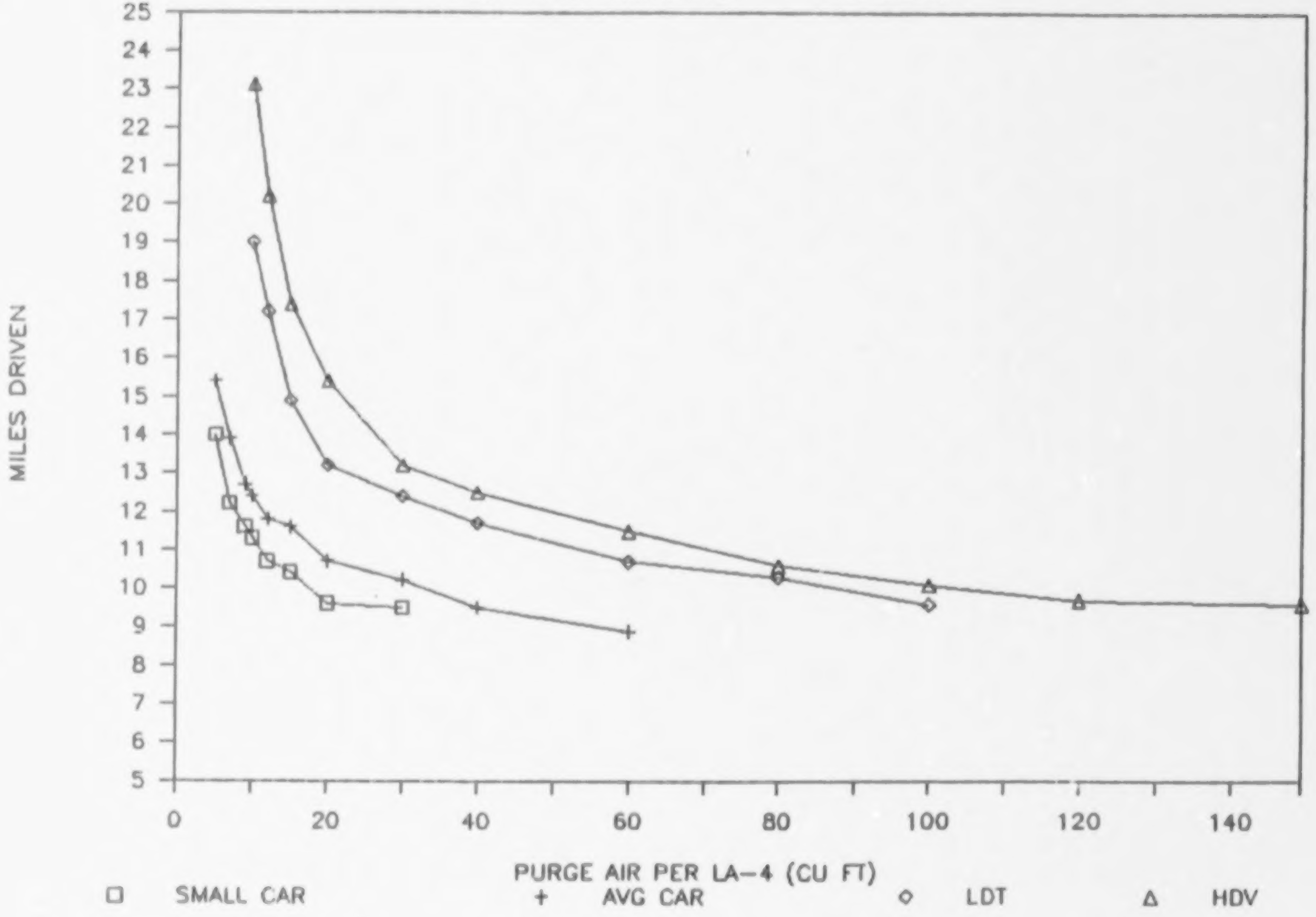
While greatly reducing resource impacts from the original draft procedure, multiple repetitions of the "daily" operating sequence will still be somewhat time and facility intensive. Remembering that continuous vehicle driving (i.e., no hot soaks or diurnals) will result in rapid purging of the canister, EPA investigated this approach as another alternative for canister conditioning. The computer model was used to determine the number of continuous LA-4 miles required to achieve canister purging equivalent to the cyclic drive stabilization level. The results of this evaluation, plotted as continuous LA-4 miles versus purge air flow rate, are shown in Figures 28 through 31 for the systems previously evaluated.

As can be seen from these figures, the number of continuous LA-4 miles required to reach the canister stabilization level is under 20 miles in most cases, although it goes as high as 33 miles for heavy-duty vehicles with very low purge rates. Relative to the "daily" cyclic drive conditioning procedure, the continuous drive procedure would provide significant savings in both time and facilities.

As envisioned for the test procedure, the continuous drive would operate as follows. Following canister loading, the vehicle would be driven continuously over repetitive LA-4 cycles until the stabilized level was reached. In the case of a partial cycle needed to complete the required mileage, the vehicle would be stopped at the first idle point after reaching the desired mileage. The refueling test would then be performed. The number of miles to be driven would be based upon previous testing to establish equivalence with the cyclic

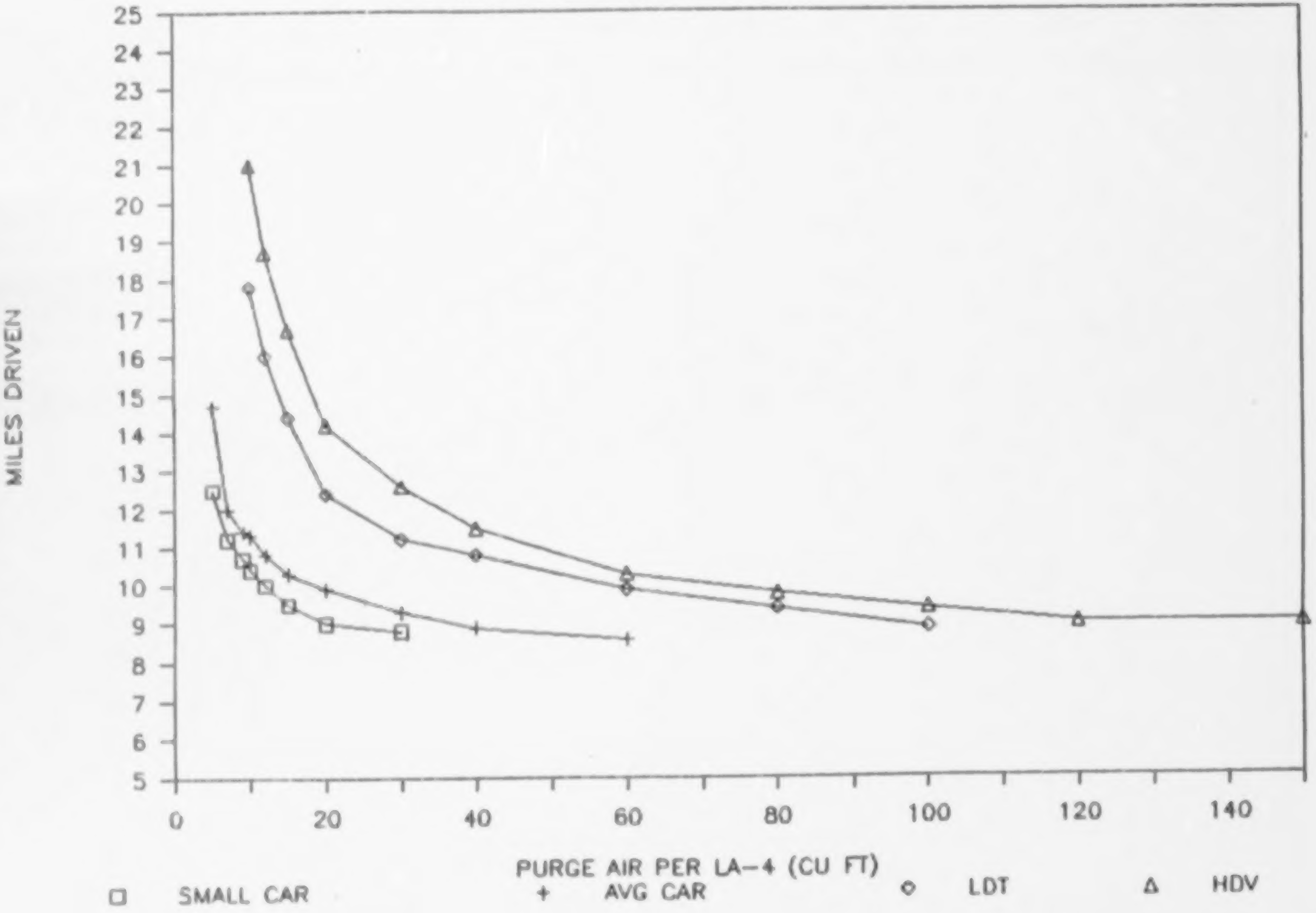
CONTINUOUS DRIVE MILES FOR PURGE

FORD TYPE CANISTER FI FIGURE 28



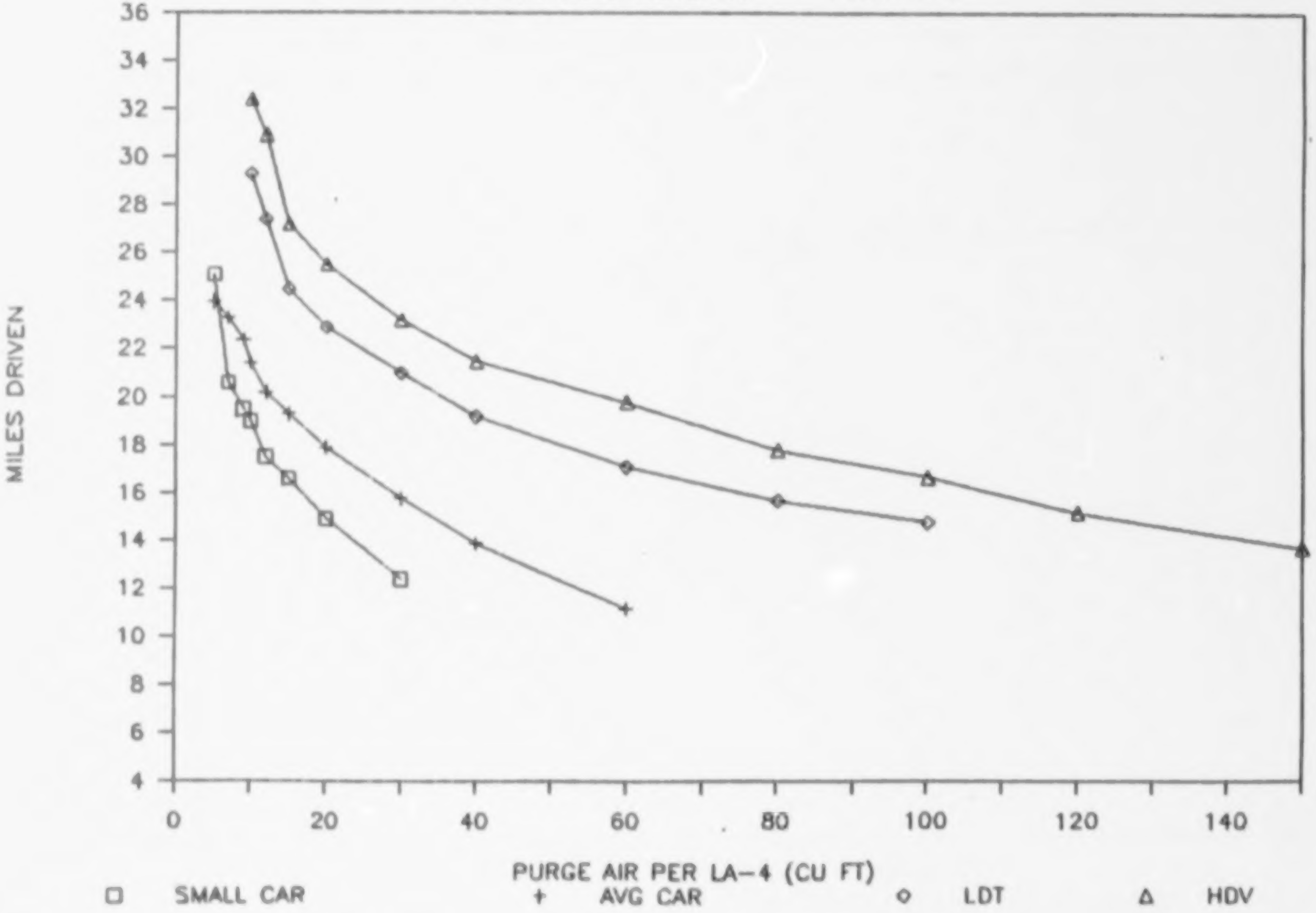
CONTINUOUS DRIVE MILES FOR PURGE

FORD TYPE CANISTER CARB. FIGURE 29



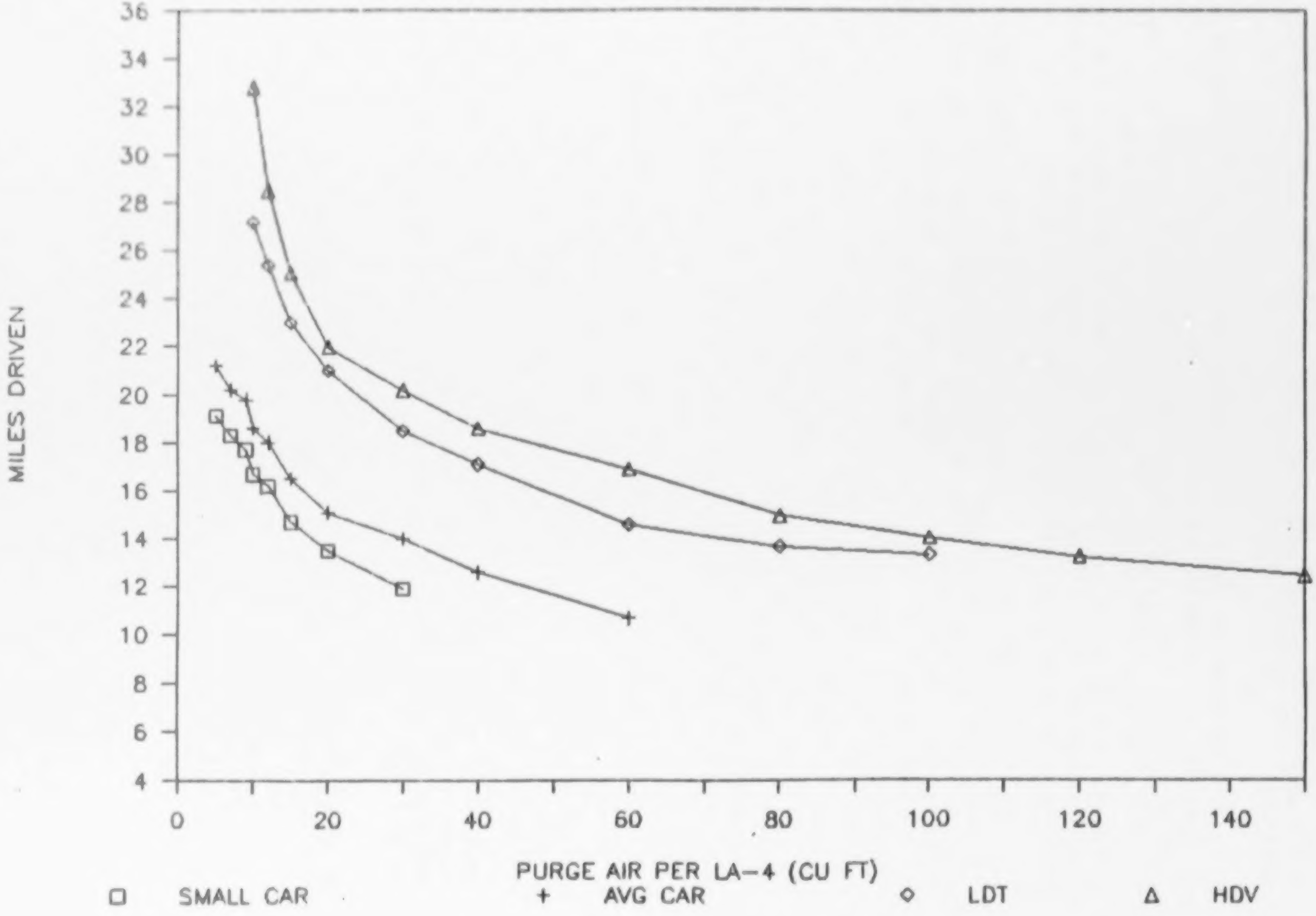
CONTINUOUS DRIVE MILES FOR PURGE

NISSAN TYPE CANISTER FI FIGURE 30



CONTINUOUS DRIVE MILES FOR PURGE

NISSAN TYPE CANISTER CARB. FIGURE 31



drive. Based, as it would be, upon the purge level developed by the cyclic drive, this test would not be a fully independent operation. Rather, it would be an abbreviated approach to obtaining the same results as the cyclic drive. It could be used by manufacturers in repeated testing of the same or substantially similar vehicles, and by EPA in all phases of its testing.

The continuous drive will allow canister conditioning with a greatly abbreviated procedure. Because of this, it would likely serve as the principal approach used by EPA. Manufacturers, once they had initially conducted the cyclic test in order to develop the appropriate continuous drive mileage, would also be able to use the continuous drive cycle for subsequent repetitive work. The continuous drive procedure should give equivalent results to the cyclic drive.

On the other hand, the continuous drive procedure has the limitation that it does not itself physically demonstrate that the control system has the ability to actually purge hot soak and diurnal loads. Thus, in spite of its advantages in terms of resource impacts, the continuous drive cannot be the only preconditioning sequence. However, so long as the cyclic drive-down is also retained, EPA would in all likelihood be able to use the continuous drive-down for the bulk of its testing. The longer cyclic procedure would be reserved for those cases when the Agency felt the need to fully demonstrate system performance via direct testing. Overall then, the revised refueling procedure will specify both preconditioning sequences with the requirement that any vehicle be able to pass the test regardless of which is used.

7.3 Conditioning of Non-Integrated Control Systems

Throughout the preceding analysis, the use of fully integrated refueling and evaporative emission controls has been assumed. That is, the analysis has presumed that the same canister is used to collect and store hot soak, diurnal and refueling emissions*. Since manufacturers may elect to use one canister dedicated to the collection and storage of refueling vapors alone and another canister for hot soak and diurnal emissions, conditioning of these canisters will be addressed at this time.

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* The preceding analysis is also applicable to systems wherein the refueling canister is used to collect either hot soak or diurnal emissions (i.e., partially integrated sytems).

Since the refueling canister in a non-integrated system may not experience hot soak or diurnal loadings, purging would be the same whether the vehicle was driven continuously or under cyclic conditions. Such a system would also not be expected to come to an equilibrium condition since each drive would continue the process of purging the canister to lower and lower levels. Thus, the only way to fully simulate conditions of a nearly empty fuel tank would be to actually drive out the required amount of fuel, beginning with a loaded canister and a full fuel tank. Since the refueling emissions measurement is initiated from the 10 percent tank volume level and fueling is continued until the fuel level in the tank is at least 95 percent of tank volume, the continuous drive duration for non-integrated systems would have to be the mileage corresponding to the consumption of fuel equal to 85 percent of fuel tank volume.

A full drive-down for non-integrated systems would be a time and resource intensive process. In addition, given the non-linear nature of the purge process (refer to the canister purge curves given in Figure 3) most of the purge would actually be accomplished in the initial phases of the drive-down. An alternative procedure, therefore might be a partial drive-down of perhaps 30 to 40 percent of tank volume followed by a nearly full refueling. Since this procedure would not directly verify full system performance, it would have to remain as an optional test, similar to the short continuous drive for integrated systems. It might also be coupled with supporting test data or engineering analysis to demonstrate that satisfactory performance at the intermediate level would be expected to result in full performance on a full test. The potential use of this option has not yet been analyzed in detail to determine adequate drive miles and fill amounts. Such an analysis is planned for the future.

F. Miscellaneous Issues

In addition to the comments addressed above, comments were provided on several other areas of the recommended test procedure. These areas included the baseline refueling emission factor, provisions for retests, vehicle temperature prior to the refueling test, specifications for refueling nozzles, and numerous other minor comments.

The California Air Resources Board (CARB) took issue with the baseline refueling emission factor. CARB stated that data collected in California from refuelings of in-use vehicle at service stations showed refueling emission factors of 3.7 g/gallon with 8.0 RVP summer fuel and 5.6 g/gallon with 12.0 RVP winter fuel for an average of 4.5 g/gallon. CARB went on to state that a national refueling control program should be based on the California annual average value of 4.5 g/gallon rather than the 5.9 g/gallon value used by EPA for 12.6 RVP summer refuelings. The purpose of this approach was to achieve a lower refueling emission standard under a fixed percent reduction approach.

EPA does not agree with CARB's analysis. First, EPA does not believe that it can equate refueling emissions measured at service stations under unknown measurement conditions to emissions measured under controlled laboratory conditions such as are included in the draft procedure and described in EPA's report, "Refueling Emissions from Uncontrolled Vehicles." This report details EPA's baseline program to measure refueling emissions and EPA will continue to use the baseline refueling emission factor resulting from its baseline program. Second, the CARB comment appears to focus on achieving the lowest possible numerical emission standard associated with a 95 percent reduction of baseline emissions. The EPA standard is not intended to be a simple percent reduction of the baseline refueling emissions. The refueling standard will be chosen to be a measurable and reasonable level as near to zero emissions as is possible. Thus, a change in the baseline emission level would not automatically result in a change in the standard.

In commenting on the need for retests, MVMA stated that the recommended procedure did not provide a clearly identifiable route for the performance of a retest of one segment, e.g., tailpipe emissions measurement, of the overall procedure either because of a test void or a failure in one segment of the test. A clear line of demarcation between the refueling segment and other segments of the overall procedure was requested.

The draft test procedure report discussed provisions to rerun tests if needed. For the refueling tests, there were several appropriate places identified where partial testing could be restarted to avoid having to rerun the entire sequence in case of a test void in one segment of the test. The revised refueling procedure is now completely separable from the exhaust and evaporative test procedures, providing the clear line of demarcation requested by MVMA. In the event that a retest of the evaporative or exhaust test were to be required, the retest would be initiated at the first step in the vehicle preparation procedure with the requirement to re-load the canister(s) prior to the 40 percent fueling for the prep LA-4 preceding the cold soak.

A concern regarding the test vehicle's temperature prior to the refueling test was noted by Toyota. To preclude inclusion of evaporative emissions into the refueling emission measurement, Toyota recommended that the test vehicle be cooled to soak area temperature prior to performing the refueling emission measurement test. This is a valid point, and in response the procedure will be modified to include the stabilization of the vehicle temperature at the soak area temperature. This will be achieved by soaking the vehicle, following the preconditioning of the canister, for a minimum of 6 hours and a maximum of 24 hours.

Two commenters stated that a specification was needed for the accuracy of the dispensed fuel meter. EPA agrees with these comments and is including a dispensed fuel meter accuracy specification in the revised procedure.

In addition to comments about limiting the dispensed fuel flow rate reviewed earlier in Section II A, a number of manufacturers commented on the need to control refueling nozzle specifications. These applied to both in-use and test nozzles, in areas of the nozzle which could impact the effectiveness of onboard control. Examples of the areas of nozzle design which could be considered for standardization under a uniform specification focus on the nozzle spout and include length, angle of bend in the spout and its location along the length of the spout, and position of the automatic shut-off port. Presently there are no standardized specifications applicable to these areas of the nozzle.

EPA is concerned about the impact that nozzle geometry may have on refueling emissions, but has little data at present with which to evaluate these claims. If it were true that nozzle geometry could substantially affect the performance of refueling systems, then a standardized design might be considered. If this were the case, such standardization would have to be applied both to test equipment and to in-use nozzles. Otherwise, refueling system performance would suffer in practice.

Lacking detailed information, no decision can be made on this issue at present. The submission of test data demonstrating the degree of sensitivity involved would be especially useful. It would also be necessary to determine to what degree fill neck designs could be modified to accept greater nozzle variability.

Finally, numerous minor comments were provided. Examples of these minor comments include recommendations for the expansion of the tolerance bands for the hot soak times and the driver trace during the canister conditioning drive to facilitate testing and to avoid unnecessary test voids. These types of comments are addressed by minor changes, where appropriate, in the test procedure.

III. Test Procedure Overview Summary

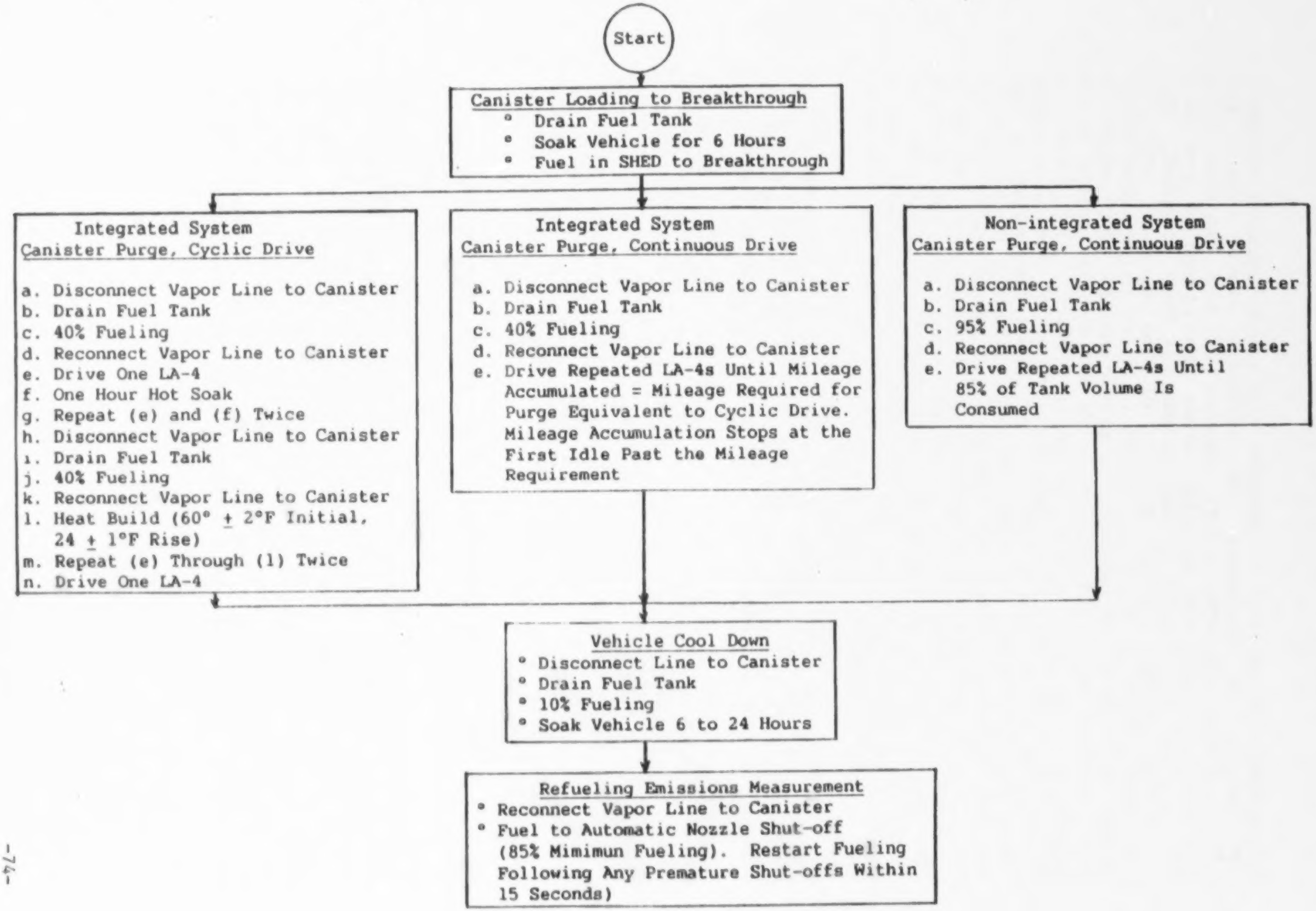
A. Onboard Test Procedure

The onboard refueling emission test procedure, resulting from the preceding reanalysis would consist of four basic steps. In the first step, the onboard canister would be loaded to at least breakthrough. The second step in the procedure would be canister purging to the appropriate level by means of the applicable vehicle drive. The third step would be vehicle cool down to ambient temperature followed by the fourth step wherein the refueling emissions are measured. The details of the tasks performed within each of these steps are shown in Figure 32.

Briefly, the execution of the procedure as shown in Figure 32 would be as follows. In the canister loading to breakthrough step, the vehicle, in as-received condition, is brought into the laboratory and the fuel tank is drained. The vehicle is soaked for six hours in the laboratory to bring the temperature of the vehicle into equilibrium with the laboratory ambient temperature. Following temperature equilibration, the vehicle is moved into the SHED and fuel is added to the fuel tank until canister breakthrough is detected. In those cases where the canister loading is already at or beyond breakthrough in the as-received condition (such as might occur during testing of in-use vehicles), the analyzer response to hydrocarbons emanating from the canister would closely coincide with the initiation of fueling and little fuel would have to be added to the fuel tank for the purpose of loading the canister.

Upon completion of the canister loading step of the procedure, the vehicle will enter into the canister purge step. In the canister purge step, the procedure which will be followed will depend, first, on whether the vehicle is equipped with an integrated or a non-integrated emission control system and second, if an integrated system is employed, whether the cyclic drive procedure or the continuous drive procedure has been selected. In Figure 32, the blocks headed "Integrated System Canister Purge, Cyclic Drive" and "Integrated System Canister Purge, Continuous Drive" are applicable to integrated systems and specify the details of the steps in each of these purge procedures. The block headed "Non-integrated System Canister Purge, Continuous Drive" specifies the details of the purge procedure for non-integrated systems.

In each of the purge procedures, the first steps are the same, i.e., to disconnect the canister vapor line to avoid disturbing the canister loading, to drain the fuel tank, to fuel with the specified volume of fuel (40 percent for


Start
Canister Loading to Breakthrough
° Drain Fuel Tank
° Soak Vehicle for 6 Hours
° Fuel in SHED to Breakthrough
Integrated System
Canister Purge, Cyclic Drive
a. Disconnect Vapor Line to Canister
b. Drain Fuel Tank
c. 40% Fueling
d. Reconnect Vapor Line to Canister
e. Drive One LA-4
f. One Hour Hot Soak
g. Repeat (e) and (f) Twice
h. Disconnect Vapor Line to Canister
i. Drain Fuel Tank
j. 40% Fueling
k. Reconnect Vapor Line to Canister
l. Heat Build (60° ± 2°F Initial, 24 ± 1°F Rise)
m. Repeat (e) Through (l) Twice
n. Drive One LA-4
Integrated System
Canister Purge, Continuous Drive
a. Disconnect Vapor Line to Canister
b. Drain Fuel Tank
c. 40% Fueling
d. Reconnect Vapor Line to Canister
e. Drive Repeated LA-4s Until Mileage Accumulated = Mileage Required for Purge Equivalent to Cyclic Drive. Mileage Accumulation Stops at the First Idle Past the Mileage Requirement
Non-integrated System
Canister Purge, Continuous Drive
a. Disconnect Vapor Line to Canister
b. Drain Fuel Tank
c. 95% Fueling
d. Reconnect Vapor Line to Canister
e. Drive Repeated LA-4s Until 85% of Tank Volume Is Consumed
Vehicle Cool Down
° Disconnect Line to Canister
° Drain Fuel Tank
° 10% Fueling
° Soak Vehicle 6 to 24 Hours
Refueling Emissions Measurement
° Reconnect Vapor Line to Canister
° Fuel to Automatic Nozzle Shut-off (85% Mimimun Fueling). Restart Fueling Following Any Premature Shut-offs Within 15 Seconds)

ONBOARD TEST PROCEDURE FLOW CHART

FIGURE 32

integrated systems and 95 percent for non-integrated systems) and finally to reconnect the canister vapor line. For non-integrated systems actual purging of the canister will consist of driving the vehicle, using repetitions of the LA-4 cycle, until 85 percent of tank volume has been consumed. For integrated systems, actual purging of the canister will be performed either by a short continuous drive using repetitions of the LA-4 until the canister is purged to the level equal to that achieved with the cyclic drive or by the cyclic drive procedure. In the cyclic drive procedure, the LA-4 is performed three times with each performance of the LA-4 being followed by a one hour hot soak. Following completion of the third LA-4/hot soak, the canister vapor line is disconnected, the fuel tank is drained and fueled to 40 percent with chilled fuel, the vapor line is reconnected and a diurnal heat build is performed. The three LA-4, three hot soaks and one diurnal heat build cycle is repeated twice and is followed by the performance of one LA-4. At this point, the canister purge drives have been completed and the vehicle enters the cool down step of the procedure.

In the cool down step, the vapor line is disconnected to ensure that canister loading is not disturbed, the fuel tank is drained and fueled with 10 percent fuel and the vehicle is allowed to cool to laboratory temperature for 6 to 24 hours.

Measurement of refueling emissions is the final step of the procedure and follows the cool down step. In the refueling emissions measurement step, the vapor line is reconnected and the vehicle is placed in the SHED. The SHED is sealed and an initial measurement of the hydrocarbon level in the SHED is made. The vehicle is fueled in the SHED with at least 85 percent of the tank volume of fuel. The final hydrocarbon level in the SHED is measured. The 85 percent fueling and the final hydrocarbon measurement are the last two steps in the refueling test procedure.

B. Associated Changes to Present Test Procedures

Existing test procedures for the measurement of evaporative and exhaust emissions were developed prior to any consideration of onboard refueling controls. Since these procedures (evaporative and exhaust tests for LDVs and LDTs and evaporative tests for HDGVs) include two forty percent tank volume fuelings, changes to account for the effects of onboard controls are necessary to achieve continuity in the results of these tests. The necessary changes are the disconnecting of the fuel tank to canister vapor lines prior to each fuel tank drain and forty percent fueling event and the reconnecting of the lines following each forty percent fueling. These disconnecting and reconnecting events will ensure that new and non-representative canister loadings are not incorporated into existing test procedures. Specifically, within the test procedure, disconnecting the vapor lines would occur first when the test vehicle enters a test program and residual fuel is to be drained and the first forty percent fueling is performed prior to the preconditioning drive and cold soak and second immediately prior to the second fuel tank drain and fueling with chilled fuel in preparation for the heat build.

In addition to the previously indicated changes three other changes to existing test procedures are proposed. The first of these changes is the addition of two steps at the start of all testing on vehicles undergoing evaporative and/or exhaust emissions testing. These two steps are a fuel tank drain and a six-hour vehicle temperature equilibration soak at a room temperature of between 68°F and 86°F. The second of these changes is the requirement that all canisters be loaded to at least breakthrough prior to the performance of the preconditioning drive for LDV and LDT evaporative and exhaust emissions tests and prior to the preconditioning drive for HDV evaporative emissions tests. The third change is the requirement that all applicable canisters be installed and operational during the performance of HDGE exhaust emission testing. Prior to being instated on the HDGE undergoing testing, the canisters are required to be loaded with hydrocarbons to a level equal to that existing at the end of the diurnal heat build in the HDGV evaporative emission test procedure; i.e. the loading resulting from a loading to breakthrough, followed by a vehicle preconditioning drive, followed by a vehicle cold soak and finally followed by a diurnal heat build.

Appendix

Evaluation of the Purge Response Characteristics of Activated Carbon Canisters

I. Introduction

EPA is currently in the process of developing a procedure to test the performance of refueling emission control systems. Regardless of the specifics of the procedure, it must evaluate; 1) the hydrocarbon storage capacity of the system and 2) the ability of the system to restore that capacity between refuelings. Testing the hydrocarbon storage capacity of the system is relatively straightforward, but testing the ability of a system to restore that capacity is significantly more complex.

The standard hydrocarbon storage medium used in today's evaporative emission control systems is activated carbon, and it appears likely that activated carbon would be used for refueling emission control as well. The Draft Recommended Test Procedure for the Measurement of Refueling Emissions published in July 1985 was developed with limited detailed information about the purge characteristics of activated carbon beds.[2] The test of purge capacity was developed around a general knowledge of the stripping characteristics of activated carbon beds, i.e. that for a given purge air flow, the rate at which hydrocarbons are stripped from the carbon bed is high when the bed is heavily loaded with hydrocarbons and this rate decreases as the hydrocarbon load is reduced. Since its publication, the proposed procedure has been further analyzed. This analysis has lead EPA to the conclusion that the procedure as originally proposed would not adequately test control system purge capability. In order to develop a procedure which does evaluate the purge capability of the control system, a better understanding of the desorption characteristics of activated carbon was needed. The test program described in this appendix was undertaken for this purpose.

The rate at which hydrocarbons are stripped from an activated carbon canister is influenced by several variables. Some of these are associated with the canister design and include; 1) size, 2) shape, 3) carbon base (the material from which the carbon is produced) and 4) internal configuration (how the vapors are routed through the carbon bed). Other variables, such as purge air flow rate and purge temperature are related to the purge process. The main body of this test program addressed the canister-related variables by evaluating the purge characteristics of several canisters of different sizes, designs, etc. Although no attempt was made to isolate the impact that individual variables had on canister performance, the data were used to estimate the variability in purge response that could be expected among different canisters. In addition to the evaluation of the purge characteristics of several canister designs, the effects of temperature, purge air flow rate and canister aging on hydrocarbon stripping were also investigated to a limited extent.

II. Test Procedure

The basic objective of this test program was to evaluate the hydrocarbon desorption characteristics of various activated carbon canisters when loaded with refueling emissions. There were two basic steps used in testing the desorption characteristics of carbon canisters. The first step involved loading the canisters to an appropriate level with the chosen hydrocarbons - in this case refueling vapors. The second step was to draw air over the carbon bed to purge it of its hydrocarbon load. During purging, the change in hydrocarbon load was measured as a function of the volume of purge air pulled over the carbon bed. Each of these steps is described in greater detail below.

A. Canister Loading

In order to evaluate the stripping characteristics of an activated carbon canister, the canister must first be loaded with hydrocarbons. Because adsorption and desorption are mechanical processes they are affected by the size of the molecules being adsorbed or desorbed. Therefore, the purge characteristics of a carbon bed can be affected by the type of hydrocarbons used to load the canister. Because the information gathered in this program is being used in the development of a procedure to test the performance of refueling emission control systems, canisters were loaded with refueling emissions.

Refueling emissions were generated by dispensing fuel with a volatility of approximately 11.5 psi RVP into a fuel tank for a 1983 Cutlass Supreme. The fillneck for this fuel tank was modified so that a tight seal was formed between the fillneck and the fuel dispensing nozzle when the nozzle was inserted into the fillneck. The fuel sender unit for this tank was also modified by adding an orifice and nipple to which a $^{5}/_{8}$" vapor line could be attached. This vapor line routed the vapors displaced during the refueling event to the carbon canister.

The performance of a canister during purge is also affected by the extent to which the canister is loaded. The more fully loaded the canister is, the higher the rate at which hydrocarbons will be removed by a given volume of purge air. Therefore, to compare the results of various tests, it is desirable to load all canisters to the same extent. This program was designed to evaluate the performance of activated carbon canisters over their normal range of hydrocarbon loading. Therefore, it seemed logical to load the canisters to approximately the "breakthrough" point. The breakthrough point is that point at which the canister can no longer adsorb all of the hydrocarbon being put into it, and some hydrocarbon passes through the canister. Although breakthrough is easy to define in theory, there are several methods of defining a practical measure of breakthrough, each of which could result in a somewhat different canister load for a given canister. In this program, the breakthrough point was detected using a flame ionization detector from an exhaust gas analyzer. Initially, the analyzer probe was placed near the canister outlet and the hydrocarbon concentration of the gas leaving the canister was monitored during the loading process. When a sharp, persistent rise in hydrocarbon content was observed, canister loading was discontinued.

During the early stages of the test program, some variability was observed between canister loadings for tests performed on the same canister loaded to the same breakthrough point. It was hypothesized that this variability was due to the technique used to determine breakthrough, i.e. that because the FID pickup was located so near the canister outlet that intermittent "spikes" of HC coming through the canister prior to breakthrough might have been mistaken for breakthrough in some instances. In an attempt to get more repeatable canister loadings, the test procedure was changed somewhat. Instead of measuring a breakthrough point for each test on a canister, a breakthrough point was only measured for the first test on the given canister. For each subsequent test on that canister, the canister was loaded with the vapors displaced by dispensing the same number of gallons of fuel that were dispensed in the original test.

B1. Canister Purge

Hydrocarbons can be stripped from a carbon bed by passing hydrocarbon-poor gas over the bed. In this program, purge was accomplished by using a vacuum source to pull air over the carbon bed. In the purge characterization portion of the test program, both the canister ambient and purge air temperatures were maintained at 95° F. Purge air flowrate was measured using a rotometer downstream from the canister. The rotometer read in standard cubic feet per minute and was monitored throughout the canister purge. A valve was installed in the air supply line downstream from the rotometer and was adjusted throughout the purge process to maintain the desired purge air flowrate. Most of the testing was performed using a flowrate of approximately one cfm, although flowrates of one half and two cfm were used in the investigation of the effects of purge air flow rate on the rate of hydrocarbon removal.

B2. Measurement of Canister Loading

The performance of an activated carbon canister can be defined in terms of the change in canister loading as a function of the volume of purge air that is pulled through the canister. Changes in canister loading were measured by weighing the canister before and after loading and at several points during the purge process. The difference in the canister mass between weighings is equal to the change in canister load. Because hydrocarbons are more easily stripped from the carbon bed when the bed is heavily loaded, data were collected more frequently during the initial portion of the purge process. Canisters were weighed at the following times*:

> 0,1,2,3,4,5,7,9,11,13,15,20,25,35,50,70, and every twenty minutes thereafter as needed.

After completion of the test program a procedural error was discovered. Specifically, the time clock was not stopped when the canisters were disconnected from the purge line for weighing, the clock was allowed to continue running for the 5-10 seconds that elapsed during each weighing. The consequence of this error is that slightly less purge air actually passed through the canisters than is represented in the data tables accompanying this report. Although this data recording practice skews the results, it should skew all the results in the same direction and approximately the same amount for tests in which the purge air flow rate is similar. To compare tests done at different flow rates, the data must be adjusted by shifting the data to account for the time lost during each canister weighing.

The only time this issue becomes important in this program is in the evaluation of purge rate on stripping characteristics. One canister was purged at three different purge rates in order to compare the effect of purge rate on hydrocarbon stripping characteristics. A ten second gap in the purge at 2 cfm represents four times as much purge air as does a ten second gap in the purge at 1/2 cfm. In order to compare the results of tests done at different purge rates, the results were corrected by shifting each data point to account for the gaps in purge air flow corresponding to canister weighings. It was estimated that each weighing took approximately ten seconds and that the canister was first disconnected after 55 seconds of purge. The correction procedure is more throughly described in the discussion of the results of the tests dealing with purge rate.

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* Because flowrate is constant, time elapsed between canister weighings is proportional to the amount of air passing through the canister in that time interval.

III. Canisters

Ideally, the results of this test program would provide a characterization of the performance of typical refueling emission control canisters that had been well aged on refueling vapors (i.e. they would previously have been subjected to multiple refueling vapor loadings and subsequent purges) and had been well maintained. Since vehicles do not presently have refueling control systems, refueling canisters were unavailable. However, evaporative emission control canisters, which perform essentially the same function, have been used for more than a decade. The question then became one of finding several canisters that could be expected to be in good condition - that is well maintained in use. One source of such canisters is the fleet of vehicles used by automobile manufacturers to gather emission control system durability and deterioration information - durability data vehicles. These vehicles are operated for 50,000 miles and are well maintained and serviced during this mileage accumulation. However, although the canisters on the durability vehicle were subjected to a great deal of mileage accumulation, the canisters were probably not as well aged as a typical in-use canister. Durability vehicles typically accumulate mileage while operating on the AMA driving cycle. This cycle consists of essentially continuous operation with infrequent stops. This kind of operation results in infrequent loading and more extensive purge than would normally occur.

Although the durability canisters may not have been fully aged, they were the best canisters readily available for use. Three domestic automakers (Chrysler, Ford, and General Motors) and one foreign maker (Nissan) were contacted and asked to supply EPA with a canister from a durability data vehicle. All of these manufacturers obliged.

A description of each of the canisters from the durability-data vehicles (durability canisters) is provided in Table A1. Most of the information provided in the table is self-explanatory, but one item deserves some further attention. That is the item labeled "Treatment after 50K Testing". As discussed above, these canisters were taken off of durability data vehicles that had accumulated 50,000 miles. Upon completion of durability mileage accumulation and testing, manufacturers typically store these vehicles in case the vehicles are needed for any further testing. It can be seen that at least three of the vehicles had been stored outside between the time they finished mileage accumulation and the time their canisters were removed. Also, one manufacturer ran the durability vehicle on the test track prior to removing the canister. The significance of this information is discussed in the analysis of the test results.

Table A1

Description of Canisters

	Chrysler	Ford	GM	Nissan	EPA
Canister Size (ml)	1320	925	850	1230	5000
Activated Carbon Base	Wood	Coal	Wood	Coconut	Wood
Design Butane(1) Working Capacity(gm)	50	50	35	57	260
Estimated Design(2) HC Working Capacity(gm)	30-35	30-35	20-25	34-40	160-180
Approximate Observed HC Working Capacity(gm)	31	33	35	57	190
Vehicle Type	S-Body (Caravan, Voyager)	Taurus(3)	J-Car (Sunbird)	Maxima	--
Canister Shape	Cylindrical	Rectangular	Cylindrical	Cylindrical	Cylindrical
Open/Closed Bottom	Closed	Closed	Open	Open(4)	Open
Treatment After 50K Testing	No Information Available	Completed 50K Jan 85 Stored outdoors on vehicle until 8/28/85 Vents covered with tape when removed from vehicle. No special treatment after removal.	Completed 50K 7/19/85 Stored outdoors on vehicle until 9/5/85 4 hrs AMA mileage accumulation (92 miles) prior to canister removal and delivery	Completed 50K Jan 84 Stored outdoors until 10/85. No special treatment after removal	--

1. These are "Design Working Capacities" as given in CERT application. Those that specify, specify Butane W.C.
2. 60-70% of "Design Butane Working Capacity"
3. Vehicle representing a Taurus.
4. Open bottom with a cover over bottom with a 5/8" opening for air to enter.

Two other canisters were tested in addition to the durability canisters. One was a new 925 milliliter Ford canister of the same design as the Ford durability canister. The results of the tests on the new canister are used in comparison with results of the Ford durability canister to evaluate the effects of aging. The sixth canister evaluated in this program was a canister built by EPA for refueling tests. This canister was not actually tested as part of this test program, nor was the purge procedure used identical to that used in testing the other canisters. It was, however, loaded with refueling vapors and purged at approximately 2 cfm. The canister is cylindrical with a volume of about five liters (h = 16 cm, r = 10 cm). The canister was loaded with Westvaco extruded activated carbon. Although this canister was not fully aged prior to the start of this program, it had been exposed to several refueling vapor loading/purge cycles as part of another project. The results of tests on this canister were used to compare results from a large canister to those from the smaller evap canisters.

IV. Results

The data obtained in the test program are presented in Tables A2-1 through A2-20. Within the tables, the data are organized by canister. For each test, information is presented on; 1) refueling conditions, 2) purge conditions, and 3) canister mass as a function of purge volume. For each test, the following information is presented:

- T_{Ti}, fuel tank temperature prior to refueling (°F)
- T_{Tf}, fuel tank temperature following refueling (°F)
- T_D , dispensed fuel temperature (°F)
- Gallons of fuel dispensed (gallons)
- T_P, purge air temperature (°F)
- f, purge air flowrate (cfm)
- t, cumulative purge time elapsed prior to canister mass measurement
- Canister mass 1) prior to loading with refueling vapors, 2) following HC loading, and 3) following each purge interval.
- Cumulative decrease in canister mass at each purge interval.

V. Analysis

The main purpose of this test program was to compare the performance of activated carbon canisters of various designs under various conditions of purge temperature and flowrate. The primary information of interest was how readily the

TABLE A2-1

CHRYSLER DURABILITY TESTS

TEST NUMBER	C1	C2
FUEL TANK TEMP. PRIOR TO REFUELING (deg. F)	72	70
FUEL TANK TEMP. FOLLOWING REFUELING (deg. F)	73	73
DISPENSED FUEL TEMPERATURE (deg. F)	73	73
GALLONS OF FUEL DISPENSED	5	6
PURGE AIR TEMPERATURE (deg. F)	95	95
PURGE AIR FLOW RATE (cfm.)	1.0	1.0
CANISTER WEIGHT PRIOR TO LOADING (gms)	874.0	860

Volume of purge air (ft^3)	Canister weight (grams)	Cumulative HC purged (grams)	Canister weight (grams)	Cumulative HC purged (grams)
0	893.3	0.0	879.8	0.0
1	878.6	14.7	865.0	14.8
2	876.2	17.1	862.0	17.8
3	875.4	17.9	860.8	19.0
4	874.9	18.4	860.2	19.6
5	874.5	18.8	859.8	20.0
7	874.1	19.2	859.6	20.2
9	873.7	19.6	859.5	20.3
11	873.4	19.9	859.4	20.4
13	873.1	20.2	859.2	20.6
15	872.8	20.5	859.1	20.7
20	871.8	21.5	858.8	21.0
25	870.9	22.4	858.5	21.3
35	869.1	24.2	857.7	22.1
50	866.5	26.8	856.7	23.1
70	863.6	29.7		
90	861.2	32.1		
110	860.0	33.3		

TABLE A2-2

CHRYSLER DURABILITY TESTS

TEST NUMBER	C3	C4
FUEL TANK TEMP. PRIOR TO REFUELING (deg. F)	71	70
FUEL TANK TEMP. FOLLOWING REFUELING (deg. F)	65	65
DISPENSED FUEL TEMPERATURE (deg. F)	65	65
GALLONS OF FUEL DISPENSED	10	10
PURGE AIR TEMPERATURE (deg. F)	95	95
PURGE AIR FLOW RATE (cfm.)	1.0	1.0
CANISTER WEIGHT PRIOR TO LOADING (gms)	860	857.9

Volume of purge air (ft^3)	Canister weight (grams)	Cumulative HC purged (grams)	Canister weight (grams)	Cumulative HC purged (grams)
0	889.0	0.0	886.6	0.0
1	879.6	9.4	879.7	6.9
2	875.3	13.7	875.1	11.5
3	872.4	16.6	871.7	14.9
4	870.2	18.8	869.6	17.0
5	868.6	20.4	867.8	18.8
7	866.1	22.9	865.4	21.2
9	864.4	24.6	863.4	23.2
11	863.3	25.7	862.4	24.2
13	862.6	26.4	861.7	24.9
15	861.9	27.1	861.0	25.6
20	860.8	28.2	859.8	26.8
25	860.0	29.0	859.1	27.5
35	859.0	30.0	858.6	28.0
50	858.1	30.9	857.7	28.9

TABLE A2-3

FORD DURABILITY TESTS

TEST NUMBER	E1	E2
FUEL TANK TEMP. PRIOR TO REFUELING (deg. F)	78	75
FUEL TANK TEMP. FOLLOWING REFUELING (deg. F)	75	75
DISPENSED FUEL TEMPERATURE (deg. F)	75	75
GALLONS OF FUEL DISPENSED	8	9
PURGE AIR TEMPERATURE (deg. F)	95	95
PURGE AIR FLOW RATE (cfm)	0.5	0.5
CANISTER WEIGHT PRIOR TO LOADING (gms)	699.1	694.3

Volume of purge air (ft^3)	Canister weight (grams)	Cumulative HC purged (grams)	Cansister weight (grams)	Cumulative HC purged (grams)
0.0	725.1	0.0	719.5	0.0
0.5	716.2	8.9	707.1	12.4
1.0	713.4	11.7	703.4	16.1
1.5	711.4	13.7	701.1	18.4
2.0	709.9	15.2	699.8	19.7
2.5	708.9	16.2	698.5	21.0
3.5	707.6	17.5	697.0	22.5
4.5	706.5	18.6	696.0	23.5
5.5	705.6	19.5	695.3	24.2
6.5	705.1	20.0	694.7	24.8
7.5	704.5	20.6	694.4	25.1
10.0	703.4	21.7	693.8	25.7
12.5	702.4	22.7	693.3	26.2
17.5	700.4	24.7	692.1	27.4
25.0	698.4	26.7	691.2	28.3
35.0	696.4	28.7		
45.0	694.5	30.6		

TABLE A2-4

FORD DURABILITY TESTS

TEST NUMBER	E3	E4
FUEL TANK TEMP. PRIOR TO REFUELING (deg. F)	76	68
FUEL TANK TEMP. FOLLOWING REFUELING (deg. F)	75	73
DISPENSED FUEL TEMPERATURE (deg. F)	75	74
GALLONS OF FUEL DISPENSED	9	9
PURGE AIR TEMPERATURE (deg. F)	95	95
PURGE AIR FLOW RATE (cfm)	1.0	1.0
CANISTER WEIGHT PRIOR TO LOADING (gms)	691.2	686.3

Volume of purge air (ft^3)	Canister weight (grams)	Cumulative HC purged (grams)	Cansister weight (grams)	Cumulative HC purged (grams)
0	716.4	0.0	715.1	0.0
1	702.4	14.0	701.4	13.7
2	698.6	17.8	697.7	17.4
3	696.8	19.6	695.5	19.6
4	695.5	20.9	694.1	21.0
5	694.4	22.0	692.9	22.2
7	693.0	23.4	691.3	23.8
9	691.9	24.5	690.0	25.1
11	691.4	25.0	689.0	26.1
13	690.8	25.6	688.5	26.6
15	690.5	25.9	688.0	27.1
20	690.0	26.4	686.7	28.4
25	689.5	26.9	686.2	28.9
35	688.5	27.9	685.3	29.8
50	687.2	29.2	684.2	30.9
70	686.5	29.9	683.1	32.0

TABLE A2-5

FORD DURABILITY TESTS

TEST NUMBER	E5	E6
FUEL TANK TEMP. PRIOR TO REFUELING (deg. F)	69	69
FUEL TANK TEMP. FOLLOWING REFUELING (deg. F)	72	72
DISPENSED FUEL TEMPERATURE (deg. F)	74	74
GALLONS OF FUEL DISPENSED	9	8
PURGE AIR TEMPERATUPE (deg. F)	95	95
PURGE AIR FLOW RATE (cfm)	2	2
CANISTER WEIGHT PRIOR TO LOADING (gms)	683.1	678.2

Volume of purge air (ft^3)	Canister weight (grams)	Cumulative HC purged (grams)	Cansister weight (grams)	Cumulative HC purged (grams)
0	713.7	0.0	709.2	0.0
2	695.0	18.7	689.2	20.0
4	691.7	22.0	686.1	23.1
6	689.5	24.2	684.0	25.2
8	688.1	25.6	683.0	26.2
10	687.3	26.4	682.2	27.0
14	685.9	27.8	681.0	28.2
18	684.9	28.8	680.1	29.1
22	684.1	29.6	679.2	30.0
26	683.7	30.0	678.9	30.3
30	683.1	30.6	678.7	30.5
40	682.2	31.5	677.8	31.4
50	681.6	32.1	677.3	31.9
70	680.5	33.2	676.7	32.5
100	679.6	34.1	675.9	33.3
140	678.2	35.5	675.3	33.9

TABLE A2-6

GM DURABILITY TESTS

TEST NUMBER	81	82
FUEL TANK TEMP. PRIOR TO REFUELING (deg. F)	69	70
FUEL TANK TEMP. FOLLOWING REFUELING (deg. F)	73	73
DISPENSED FUEL TEMPERATURE (deg. F)	73	74
GALLONS OF FUEL DISPENSED	7	8
PURGE AIR TEMPERATURE (deg. F)	95	95
PURGE AIR FLOW RATE (cfm.)	1.0	1.0
CANISTER WEIGHT PRIOR TO LOADING (gms)	445.1	424.1

Volume of purge air (ft^3)	Canister weight (grams)	Cumulative HC purged (grams)	Canister weight (grams)	Cumulative HC purged (grams)
0	471.1	0.0	451.8	0.0
1	455.8	15.3	438.4	13.4
2	451.5	19.6	433.2	18.6
3	449.4	21.7	431.1	20.7
4	447.7	23.4	429.5	22.3
5	447.0	24.1	428.7	23.1
7	445.6	25.5	427.3	24.5
9	444.6	26.5	426.2	25.6
11	444.0	27.1	425.4	26.4
13	443.2	27.9	424.6	27.2
15	442.5	28.6	424.0	27.8
20	441.2	29.9	422.6	29.2
25	439.9	31.2	421.4	30.4
35	437.5	33.6	419.7	32.1
50	433.8	37.3	417.1	34.7
70	429.5	41.6	415.0	36.8
90	424.7	46.4	414.1	37.7

TABLE A2-7

GM DURABILITY TESTS

TEST NUMBER	B3	B4
FUEL TANK TEMP. PRIOR TO REFUELING (deg. F)	71	70
FUEL TANK TEMP. FOLLOWING REFUELING (deg. F)	65	65
DISPENSED FUEL TEMPERATURE (deg. F)	65	65
GALLONS OF FUEL DISPENSED	10	10
PURGE AIR TEMPERATURE (deg. F)	95	95
PURGE AIR FLOW RATE (cfm.)	1.0	1.0
CANISTER WEIGHT PRIOR TO LOADING (gms)	417.1	417.2

Volume of purge air (ft^3)	Canister weight (grams)	Cumulative HC purged (grams)	Canister weight (grams)	Cumulative HC purged (grams)
0	456.1	0.0	450.2	0.0
1	446.1	10.0	443.3	6.9
2	442.3	13.8	439.1	11.1
3	439.7	16.4	436.4	13.8
4	437.5	18.6	434.1	16.1
5	435.9	20.2	432.3	17.9
7	433.4	22.7	429.7	20.5
9	431.2	24.9	428.0	22.2
11	429.7	26.4	426.6	23.6
13	428.5	27.6	425.5	24.7
15	427.4	28.7	424.6	25.6
20	425.1	31.0	422.9	27.3
25	423.6	32.5	421.2	29.0
35	421.0	35.1	419.3	30.9
50	418.9	37.2	417.8	32.4
70	417.1	39.0	416.6	33.6
90				

TABLE A2-8

GM DURABILITY TESTS

TEST NUMBER	85	86
FUEL TANK TEMP. PRIOR TO REFUELING (deg. F)	72	73
FUEL TANK TEMP. FOLLOWING REFUELING (deg. F)	65	65
DISPENSED FUEL TEMPERATURE (deg. F)	65	65
GALLONS OF FUEL DISPENSED	10	10
PURGE AIR TEMPERATURE (deg. F)	95	95
PURGE AIR FLOW RATE (cfm.)	1.0	1.0
CANISTER WEIGHT PRIOR TO LOADING (gms)	416.8	417.6

Volume of purge air (ft^3)	Canister weight (grams)	Cumulative HC purged (grams)	Canister weight (grams)	Cumulative HC purged (grams)
0	443.8	0.0	450.6	0.0
1	437.0	6.8	442.6	8.0
2	433.9	9.9	438.7	11.9
3	431.7	12.1	435.6	15.0
4	430.0	13.8	433.3	17.3
5	428.7	15.1	432.1	18.5
7	426.9	16.9	429.3	21.3
9	425.6	18.2	427.7	22.9
11	424.6	19.2	426.5	24.1
13	423.8	20.0	425.7	24.9
15	423.2	20.6	425.0	25.6
20	421.7	22.1	423.4	27.2
25	420.6	23.2	421.9	28.7
35	419.1	24.7	420.2	30.4
50	417.6	26.2	418.5	32.1
70			417.4	33.2
90	(not used in average)			

TABLE A2-9

NISSAN DURABILITY TESTS

TEST NUMBER	01	02
FUEL TANK TEMP. PRIOR TO REFUELING (deg. F)	70	71
FUEL TANK TEMP. FOLLOWING REFUELING (deg. F)	65	67
DISPENSED FUEL TEMPERATURE (deg. F)	65	67
GALLONS OF FUEL DISPENSED	25	15
PURGE AIR TEMPERATURE (deg. F)	95	95
PURGE AIR FLOW RATE (cfm.)	1.0	1.0
CANISTER WEIGHT PRIOR TO LOADING (gms)	1103.9	1100.2

Volume of purge air (ft^3)	Canister weight (grams)	Cumulative HC purged (grams)	Canister weight (grams)	Cumulative HC purged (grams)
0	1163.3	0.0	1162.9	0.0
1	1152.9	10.4	1154.3	8.6
2	1148.3	15.0	1150.2	12.7
3	1145.1	18.2	1146.7	16.2
4	1141.7	21.6	1143.7	19.2
5	1139.0	24.3	1141.3	21.6
7	1134.8	28.5	1136.8	26.1
9	1132.0	31.3	1132.5	30.4
11	1128.9	34.4	1129.5	33.4
13	1126.5	36.8	1126.9	36.0
15	1124.4	38.9	1124.6	38.3
20	1120.4	42.9	1120.2	42.7
25	1116.8	46.5	1117.0	45.9
35	1111.3	52.0	1112.0	50.9
50	1104.9	58.4	1107.3	55.6
70	1100.3	63.0	1103.2	59.7

TABLE A2-10

NISSAN DURABILITY TESTS

TEST NUMBER	03	04
FUEL TANK TEMP. PRIOR TO REFUELING (deg. F)	66	66
FUEL TANK TEMP. FOLLOWING REFUELING (deg. F)	59	59
DISPENSED FUEL TEMPERATURE (deg. F)	59	59
GALLONS OF FUEL DISPENSED	16	16
PURGE AIR TEMPERATURE (deg. F)	95	95
PURGE AIR FLOW RATE (cfm.)	1.0	1.0
CANISTER WEIGHT PRIOR TO LOADING (gms)	1097.4	1094.1

Volume of purge air (ft^3)	Canister weight (grams)	Cumulative HC purged (grams)	Canister weight (grams)	Cumulative HC purged (grams)
0	1150.4	0.0	1145.9	0.0
1	1137.8	12.6	1138.2	7.7
2	1131.2	19.2	1133.5	12.4
3	1126.2	24.2	1130.0	15.9
4	1121.7	28.7	1126.9	19.0
5	1118.4	32.0	1124.5	21.4
7	1114.1	36.3	1120.7	25.2
9	1110.8	39.6	1117.9	28.0
11	1108.5	41.9	1115.9	30.0
13	1106.7	43.7	1114.1	31.8
15	1105.3	45.1	1112.3	33.6
20	1102.1	48.3	1109.2	36.7
25	1100.0	50.4	1107.1	38.8
35	1097.2	53.2	1103.3	42.6
50	1094.4	56.0	1098.5	47.4
70			1093.5	52.4
90			1089.7	56.2

TABLE A2-11

NISSAN DURABILITY TESTS

TEST NUMBER	05	06
FUEL TANK TEMP. PRIOR TO REFUELING (deg. F)	64	65
FUEL TANK TEMP. FOLLOWING REFUELING (deg. F)	59	59
DISPENSED FUEL TEMPERATURE (deg. F)	59	58
GALLONS OF FUEL DISPENSED	16	26
PURGE AIR TEMPERATURE (deg. F)	95	95
PURGE AIR FLOW RATE (cfm.)	1.0	1.0
CANISTER WEIGHT PRIOR TO LOADING (gms)	1086.8	1082.1

Volume of purge air (ft^3)	Canister weight (grams)	Cumulative HC purged (grams)	Canister weight (grams)	Cumulative HC purged (grams)
0	1127.4	0.0	1146.4	0.0
1	1120.2	7.2	1138.4	8.0
2	1115.8	11.6	1133.6	12.8
3	1112.8	14.6	1129.4	17.0
4	1110.3	17.1	1126.6	19.8
5	1108.4	19.0	1124.4	22.0
7	1104.9	22.5	1120.2	26.2
9	1102.5	24.9	1117.3	29.1
11	1101.1	26.3	1114.9	31.5
13	1099.6	27.8	1113.0	33.4
15	1098.0	29.4	1111.1	35.3
20	1095.4	32.0	1107.9	38.5
25	1093.8	33.6	1105.4	41.0
35	1091.1	36.3	1101.2	45.2
50	1088.1	39.3	1096.6	49.8
70	1085.1	42.3	1090.8	55.6
90	1082.7	44.7	1086.4	60.0

(not used in average)

TABLE A2-12

NISSAN DURABILITY TESTS

TEST NUMBER	07	08
FUEL TANK TEMP. PRIOR TO REFUELING (deg. F)	59	66
FUEL TANK TEMP. FOLLOWING REFUELING (deg. F)	58	60
DISPENSED FUEL TEMPERATURE (deg. F)	58	60
GALLONS OF FUEL DISPENSED	22.5	16
PURGE AIR TEMPERATURE (deg. F)	95	115
PURGE AIR FLOW RATE (cfm.)	1.0	1.0
CANISTER WEIGHT PRIOR TO LOADING	1059.1	1011.4

Volume of purge air (ft^3)	Canister weight (grams)	Cumulative HC purged (grams)	Canister weight (grams)	Cumulative HC purged (grams)
0	1119.1	0.0	1061.5	0.0
1	1114.7	4.4	1058.3	3.2
2	1112.0	7.1	1056.7	4.8
3	1109.8	9.3	1055.3	6.2
4	1107.6	11.5	1054.0	7.5
5	1105.9	13.2	1052.8	8.7
7	1102.6	16.5	1051.0	10.5
9	1099.9	19.2	1049.7	11.8
11	1098.2	20.9	1048.7	12.8
13	1096.6	22.5	1048.0	13.5
15	1095.3	23.8	1047.3	14.2
20	1092.0	27.1	1046.3	15.2
25	1089.2	29.9	1045.5	16.0
35	1084.7	34.4	1044.0	17.5
50	1079.3	39.8	1042.5	19.0
70	1073.0	46.1	1040.6	20.9
90	1068.5	50.6	1038.8	22.7

TABLE A2-13

NISSAN DURABILITY TESTS

TEST NUMBER	09
FUEL TANK TEMP. PRIOR TO REFUELING (deg. F)	67
FUEL TANK TEMP. FOLLOWING REFUELING (deg. F)	59
DISPENSED FUEL TEMPERATURE (deg. F)	59
GALLONS OF FUEL DISPENSED	16
PURGE AIR TEMPERATURE (deg. F)	115
PURGE AIR FLOW RATE (cfm.)	1.0
CANISTER WEIGHT PRIOR TO LOADING	1038.8

Volume of purge air (ft^3)	Canister weight (grams)	Cumulative HC purged (grams)
0	1093.1	0.0
1	1088.2	4.9
2	1085.5	7.6
3	1083.4	9.7
4	1081.7	11.4
5	1080.3	12.8
7	1078.0	15.1
9	1076.3	16.8
11	1075.0	18.1
13	1073.9	19.2
15	1072.7	20.4
20	1071.0	22.1
25	1069.6	23.5
35	1067.4	25.7
50	1064.8	28.3
70	1061.8	31.3
90	1058.8	34.3

TABLE A2-14

NEW FORD TESTS

TEST NUMBER	A1	A2
FUEL TANK TEMP. PRIOR TO REFUELING (deg. F)	75	69
FUEL TANK TEMP. FOLLOWING REFUELING (deg. F)	76	75
DISPENSED FUEL TEMPERATURE (deg. F)	76	75
GALLONS OF FUEL DISPENSED	12	12
PURGE AIR TEMPERATURE (deg. F)	95	95
PURGE AIR FLOW RATE (cfm.)	1.0	1.0
CANISTER WEIGHT PRIOR TO LOADING (gms)	587.9	594.7

Volume of purge air (ft^3)	Canister weight (grams)	Cumulative HC purged (grams)	Canister weight (grams)	Cumulative HC purged (grams)
0	635.8	0.0	634.7	0.0
1	620.5	15.3	619.5	15.2
2	616.5	19.3	614.8	19.9
3	614.1	21.7	612.1	22.6
4	612.1	23.7	610.3	24.4
5	610.8	25.0	609.2	25.5
7	608.8	27.0	607.5	27.2
9	607.6	28.2	606.5	28.2
11	606.4	29.4	605.7	29.0
13	605.6	30.2	605.0	29.7
15	604.9	30.9	604.4	30.3
20	603.1	32.7	602.9	31.8
25	601.7	34.1	601.8	32.9
35	599.4	36.4	599.7	35.0
50	596.8	39.0	597.5	37.2
70	594.4	41.4	595.6	39.1
90			594.4	40.3

TABLE A2-15

NEW FORD TESTS

TEST NUMBER	A3		A4	
FUEL TANK TEMP. PRIOR TO REFUELING (deg. F)	74		75	
FUEL TANK TEMP. FOLLOWING REFUELING (deg. F)	75		75	
DISPENSED FUEL TEMPERATURE (deg. F)	75		75	
GALLONS OF FUEL DISPENSED	10		12	
PURGE AIR TEMPERATURE (deg. F)	95		95	
PURGE AIR FLOW RATE (cfm.)	1.0		1.0	
CANISTER WEIGHT PRIOR TO LOADING (gms)	594.4		595.1	
Volume of purge air (ft^3)	Canister weight (grams)	Cumulative HC purged (grams)	Canister weight (grams)	Cumulative HC purged (grams)
0	634.2	0.0	630.8	0.0
1	617.4	16.8	616.8	14.0
2	613.0	21.2	614.0	16.8
3	610.4	23.8	611.1	19.7
4	609.0	25.2	609.9	20.9
5	608.0	26.2	609.0	21.8
7	606.5	27.7	607.9	22.9
9	605.3	28.9	607.2	23.6
11	604.6	29.6	606.6	24.2
13	603.9	30.3	605.9	24.9
15	603.3	30.9	605.4	25.4
20	602.0	32.2	604.4	26.4
25	600.8	33.4	603.3	27.5
35	599.1	35.1	601.4	29.4
50	597.1	37.1	599.7	31.1
70	595.8	38.4	598.3	32.5
90	594.7	39.5	597.3	33.5

TABLE A2-14

NEW FORD TESTS

TEST NUMBER	A1	A2
FUEL TANK TEMP. PRIOR TO REFUELING (deg. F)	75	69
FUEL TANK TEMP. FOLLOWING REFUELING (deg. F)	76	75
DISPENSED FUEL TEMPERATURE (deg. F)	76	75
GALLONS OF FUEL DISPENSED	12	12
PURGE AIR TEMPERATURE (deg. F)	95	95
PURGE AIR FLOW RATE (cfm.)	1.0	1.0
CANISTER WEIGHT PRIOR TO LOADING (gms)	587.9	594.7

Volume of purge air (ft^3)	Canister weight (grams)	Cumulative HC purged (grams)	Canister weight (grams)	Cumulative HC purged (grams)
0	635.8	0.0	634.7	0.0
1	620.5	15.3	619.5	15.2
2	616.5	19.3	614.8	19.9
3	614.1	21.7	612.1	22.6
4	612.1	23.7	610.3	24.4
5	610.8	25.0	609.2	25.5
7	608.8	27.0	607.5	27.2
9	607.6	28.2	606.5	28.2
11	606.4	29.4	605.7	29.0
13	605.6	30.2	605.0	29.7
15	604.9	30.9	604.4	30.3
20	603.1	32.7	602.9	31.8
25	601.7	34.1	601.8	32.9
35	599.4	36.4	599.7	35.0
50	596.8	39.0	597.5	37.2
70	594.4	41.4	595.6	39.1
90			594.4	40.3

TABLE A2-15

NEW FORD TESTS

TEST NUMBER	A3	A4
FUEL TANK TEMP. PRIOR TO REFUELING (deg. F)	74	75
FUEL TANK TEMP. FOLLOWING REFUELING (deg. F)	75	75
DISPENSED FUEL TEMPERATURE (deg. F)	75	75
GALLONS OF FUEL DISPENSED	10	12
PURGE AIR TEMPERATURE (deg. F)	95	95
PURGE AIR FLOW RATE (cfm.)	1.0	1.0
CANISTER WEIGHT PRIOR TO LOADING (gms)	594.4	595.1

Volume of purge air (ft^3)	Canister weight (grams)	Cumulative HC purged (grams)	Canister weight (grams)	Cumulative HC purged (grams)
0	634.2	0.0	630.8	0.0
1	617.4	16.8	616.8	14.0
2	613.0	21.2	614.0	16.8
3	610.4	23.8	611.1	19.7
4	609.0	25.2	609.9	20.9
5	608.0	26.2	609.0	21.8
7	606.5	27.7	607.9	22.9
9	605.3	28.9	607.2	23.6
11	604.6	29.6	606.6	24.2
13	603.9	30.3	605.9	24.9
15	603.3	30.9	605.4	25.4
20	602.0	32.2	604.4	26.4
25	600.8	33.4	603.3	27.5
35	599.1	35.1	601.4	29.4
50	597.1	37.1	599.7	31.1
70	595.8	38.4	598.3	32.5
90	594.7	39.5	597.3	33.5

TABLE A2-16

NEW FORD TESTS

TEST NUMBER	A5	A6
FUEL TANK TEMP. PRIOR TO REFUELING (deg. F)	70	69
FUEL TANK TEMP. FOLLOWING REFUELING (deg. F)	74	74
DISPENSED FUEL TEMPERATURE (deg. F)	74	74
GALLONS OF FUEL DISPENSED	10	10
PURGE AIR TEMPERATURE (deg. F)	95	95
PURGE AIR FLOW RATE (cfm.)	1.0	1.0
CANISTER WEIGHT PRIOR TO LOADING (gms)	602.4	602.8

Volume of purge air (ft^3)	Canister weight (grams)	Cumulative HC purged (grams)	Canister weight (grams)	Cumulative HC purged (grams)
0	636.3	0.0	640.8	0.0
1	622.0	14.3	628.3	12.5
2	618.8	17.5	622.0	18.8
3	616.6	19.7	620.1	20.7
4	615.3	21.0	616.2	24.6
5	614.3	22.0	614.3	26.5
7	613.0	23.3	612.8	28.0
9	612.2	24.1	611.8	29.0
11	611.4	24.9	610.7	30.1
13	610.7	25.6	610.0	30.8
15	610.1	26.2	609.3	31.5
20	608.8	27.5	608.0	32.8
25	607.6	28.7	606.8	34.0
35	606.1	30.2	604.7	36.1
50	604.6	31.7	602.7	38.1
70	603.3	33.0		
90	602.8	33.5		

TABLE A2-17

NEW FORD TESTS

TEST NUMBER	A7	A8
FUEL TANK TEMP. PRIOR TO REFUELING (deg. F)	72	71
FUEL TANK TEMP. FOLLOWING REFUELING (deg. F)	64	62
DISPENSED FUEL TEMPERATURE (deg. F)	64	62
GALLONS OF FUEL DISPENSED	13	13
PURGE AIR TEMPERATURE (deg. F)	95	115
PURGE AIR FLOW RATE (cfm.)	1.0	1.0
CANISTER WEIGHT PRIOR TO LOADING (gms)	627.4	628.1

Volume of purge air (ft^3)	Canister weight (grams)	Cumulative HC purged (grams)	Canister weight (grams)	Cumulative HC purged (grams)
0	671.5	0.0	665.8	0.0
1	660.0	11.5	662.0	3.8
2	658.6	12.9	659.4	6.4
3	657.1	14.4	657.5	8.3
4	654.3	17.2	656.1	9.7
5	651.7	19.8	654.9	10.9
7	648.2	23.3	653.2	12.6
9	646.0	25.5	651.8	14.0
11	644.4	27.1	650.9	14.9
13	642.8	28.7	650.2	15.6
15	642.1	29.4	649.6	16.2
20	640.2	31.3	648.2	17.6
25	638.8	32.7	647.3	18.5
35	636.4	35.1	646.0	19.8
50	633.8	37.7	644.4	21.4
70	631.6	39.9	643.1	22.7
90	629.9	41.6	642.0	23.8
110			640.5	25.3
130			639.1	26.7
150			637.9	27.9
170			636.6	29.2
190			635.6	30.2
210			634.7	31.1

TABLE A2-18

NEW FORD TESTS

TEST NUMBER	A9	A10
FUEL TANK TEMP. PRIOR TO REFUELING (deg. F)	67	66
FUEL TANK TEMP. FOLLOWING REFUELING (deg. F)	61	61
DISPENSED FUEL TEMPERATURE (deg. F)	61	61
GALLONS OF FUEL DISPENSED	13	13
PURGE AIR TEMPERATURE (deg. F)	115	115
PURGE AIR FLOW RATE (cfm.)	1.0	1.0
CANISTER WEIGHT PRIOR TO LOADING (gms)	634.5	635.8

Volume of purge air (ft^3)	Canister weight (grams)	Cumulative HC purged (grams)	Canister weight (grams)	Cumulative HC purged (grams)
0	674.7	0.0	667.3	0.0
1	665.0	9.7	659.5	7.8
2	659.8	14.9	656.1	11.2
3	657.5	17.2	653.6	13.7
4	655.0	19.7	651.9	15.4
5	653.7	21.0	650.7	16.6
7	651.1	23.6	648.7	18.6
9	649.5	25.2	647.3	20.0
11	648.2	26.5	646.3	21.0
13	647.2	27.5	645.6	21.7
15	646.6	28.1	644.9	22.4
20	645.0	29.7	643.6	23.7
25	643.6	31.1	642.7	24.6
35	641.9	32.8	641.0	26.3
50	639.5	35.2	639.1	28.2
70	637.8	36.9	638.0	29.3
90	636.0	38.7	637.0	30.3

TABLE A2-19

NEW FORD TESTS

TEST NUMBER	A11	A12
FUEL TANK TEMP. PRIOR TO REFUELING (deg. F)	71	67
FUEL TANK TEMP. FOLLOWING REFUELING (deg. F)	61	61
DISPENSED FUEL TEMPERATURE (deg. F)	61	61
GALLONS OF FUEL DISPENSED	13	13
PURGE AIR TEMPERATURE (deg. F)	75	75
PURGE AIR FLOW RATE (cfm.)	1.0	1.0
CANISTER WEIGHT PRIOR TO LOADING (gms)	636.5	643.4

Volume of purge air (ft^3)	Canister weight (grams)	Cumulative HC purged (grams)	Canister weight (grams)	Cumulative HC purged (grams)
0	673.9	0.0	678.2	0.0
1	668.3	5.6	671.0	7.2
2	665.7	8.2	667.2	11.0
3	663.7	10.2	664.7	13.5
4	662.1	11.8	663.0	15.2
5	661.0	12.9	661.7	16.5
7	659.0	14.9	659.5	18.7
9	657.8	16.1	657.8	20.4
11	656.8	17.1	656.9	21.3
13	656.0	17.9	655.9	22.3
15	655.5	18.4	655.1	23.1
20	653.6	20.3	653.3	24.9
25	652.9	21.0	651.8	26.4
35	650.9	23.0	649.7	28.5
50	648.6	25.3	646.8	31.4
70	645.9	28.0	643.7	34.5
90	643.4	30.5		

TABLE A2-20

NEW FORD TESTS

TEST NUMBER	A13	A14
FUEL TANK TEMP. PRIOR TO REFUELING (deg. F)	67	69
FUEL TANK TEMP. FOLLOWING REFUELING (deg. F)	61	61
DISPENSED FUEL TEMPERATURE (deg. F)	61	61
GALLONS OF FUEL DISPENSED	13	13
PURGE AIR TEMPERATURE (deg. F)	75	75
PURGE AIR FLOW RATE (cfm.)	1.0	1.0
CANISTER WEIGHT PRIOR TO LOADING (gms)	650.4	643.4

Volume of purge air (ft^3)	Canister weight (grams)	Cumulative HC purged (grams)	Canister weight (grams)	Cumulative HC purged (grams)
0	681.4	0.0	683.1	0.0
1	672.4	9.0	676.1	7.0
2	668.3	13.1	672.3	10.8
3	665.8	15.6	670.3	12.8
4	663.8	17.6	668.4	14.7
5	662.4	19.0	667.3	15.8
7	660.4	21.0	665.0	18.1
9	658.8	22.6	663.7	19.4
11	658.0	23.4	662.7	20.4
13	657.1	24.3	661.9	21.2
15	656.7	24.7	661.4	21.7
20	655.2	26.2	660.1	23.0
25	654.3	27.1	659.2	23.9
35	652.5	28.9	656.8	26.3
50	650.4	31.0	654.7	28.4
70	649.5	31.9	652.6	30.5
90			650.4	32.7

canister releases hydrocarbon in response to a given volume of purge air when purged at a given flowrate and temperature. Because the amount of HC purged does not vary linearly with the purge air volume, canister performance should be compared over a continuum rather than at any given time during the purge sequence. The simplest way to do this is with a graphical representation of the results which were presented in the previous section. Throughout the rest of the data analysis, canisters are compared by comparing plots of cumulative HC purged from the canister (ordinate) versus the cumulative volume of purge air pulled through the canister prior to the given mass measurement (abscissa). The data points were connected with a smooth curve to approximate the performance of the canister at all times in the purge sequence.

Because there is some variability in canister performance from one test to another the results from a series of tests on a given canister were averaged to find a "typical" purge curve for each series. The averages were found by finding the average amount of hydrocarbon purged from the canister at each data point. The average values were found and plotted, and a smooth curve drawn between the average values. Most of the analysis in this report is based on the average curves developed as described above.

The remainder of the analysis of results is divided into five sections. The first section addresses some differences that were observed between the first test or tests performed on a given durability canister and later tests performed on the same canister. The next section touches on the effects of canister aging by evaluating the results from sequential tests on a new canister and by comparing results of tests performed an aged (durability) Ford canister of identical design. The effect of purge rate is then briefly discussed followed by a description of the results of the tests designed to evaluate the effect of temperature on purge rate. The next section describes the most substantial portion of the work in this test program. That is the development of a "representative" purge curve for each canister type examined in this program. The final section discusses the internal temperature of the refueling canister during the purge process.

A. Initial Tests versus Average Curves

As part of the analysis of the canister test results, the results from tests performed on individual canisters under similar conditions of purge were plotted individually on the same set of axes. When plotted in this way, the results from three of the four durability canisters tested show a pattern in the test results. The pattern observed was that the shape of the curve generated from the results of the first one or two tests on a given canister was markedly different from the shape of the curve generated in subsequent tests. In two of these three cases the canister working capacity appeared to improve after the first few tests, and in the third case the canister working capacity appeared to decrease after the first few cycles.

The durability canisters supplied by Ford and Chrysler both showed a lower working capacity in the initial tests than in subsequent tests. Figure A1 shows two curves generated from the results of the tests on the Chrysler durability canister. The curve labeled "Initial" was generated by averaging the data taken in the first and second tests on the canister. The curve labeled "Average" is the average of the other two tests performed on that canister. The results of the first two tests were nearly identical to each other as were the results of the third and fourth tests. An examination of Figure A1 shows that the purge curve representing the initial tests is different from that representing later tests in terms of both working capacity (lower for initial tests) and shape. A similar pattern is seen in Figure A2. Figure A2 shows results of tests performed on the durability canister provided by Ford Motor Company. An examination of the plots shows a lower working capacity and a distinctly different pattern of purge response in the initial test as compared with later tests.

Results of the tests performed on the durability canister supplied by General Motors are shown in Figure A3. As in the tests on the Ford and Chrysler durability canisters, there is a noticeable difference between the initial tests and later tests. In this case, however, the working capacity observed in the initial test on the canister is greater than the capacity observed in succeeding tests.

The results of the initial tests on the durability canisters raised two questions: 1) Why did the initial test (or tests) on these durability canisters produce different results than subsequent tests? and 2) Why did the capacities of the Ford and Chrysler canisters apparently increase over the capacity observed in their initial tests, while the capacity of the General Motors canister appeared to decrease? One possible explanation of these results is described in the following paragraph.

An increase in canister working capacity with time suggests that the canister is being purged somewhat more fully than it recently had been, and that some hard to remove hydrocarbons are being stripped from the carbon. Conversely, a decrease in canister working capacity suggests that the canister was initially fairly well stripped, but that

FIGURE A-1

INITIAL CURVES VS. AVERAGE CURVE

Chrysler Durability

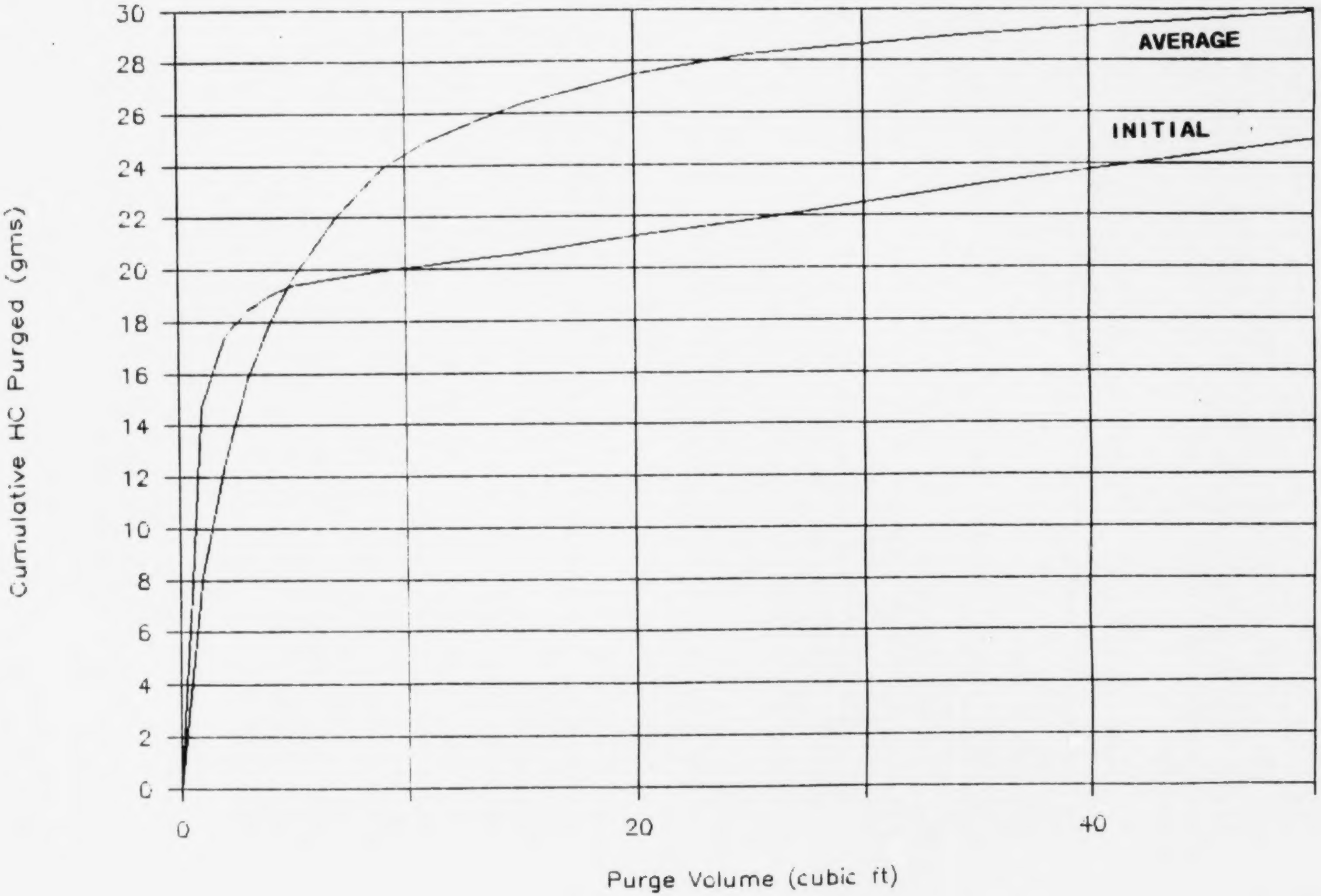


FIGURE A-2

INITIAL CURVE VS. AVERAGE CURVE

Ford Durability

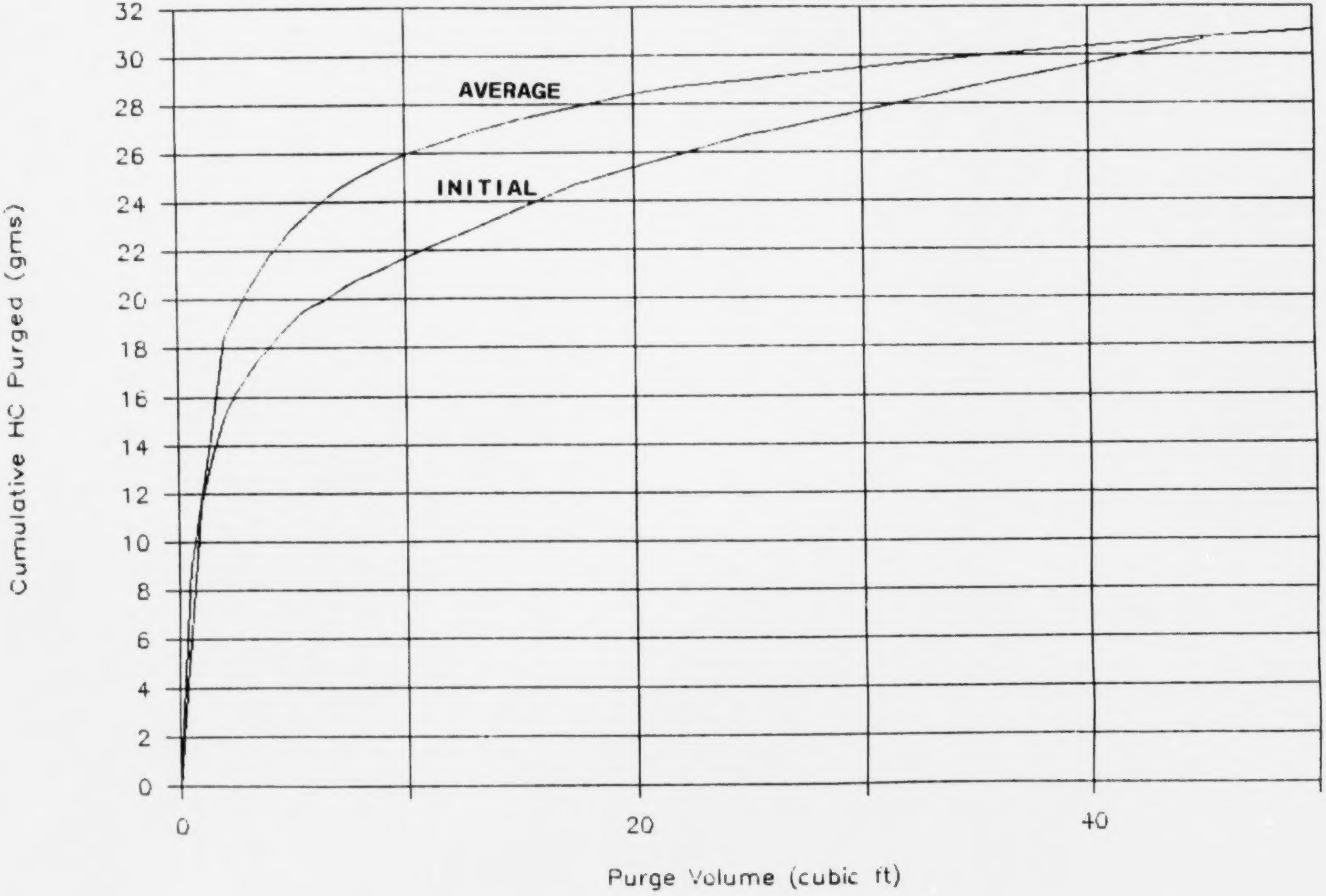
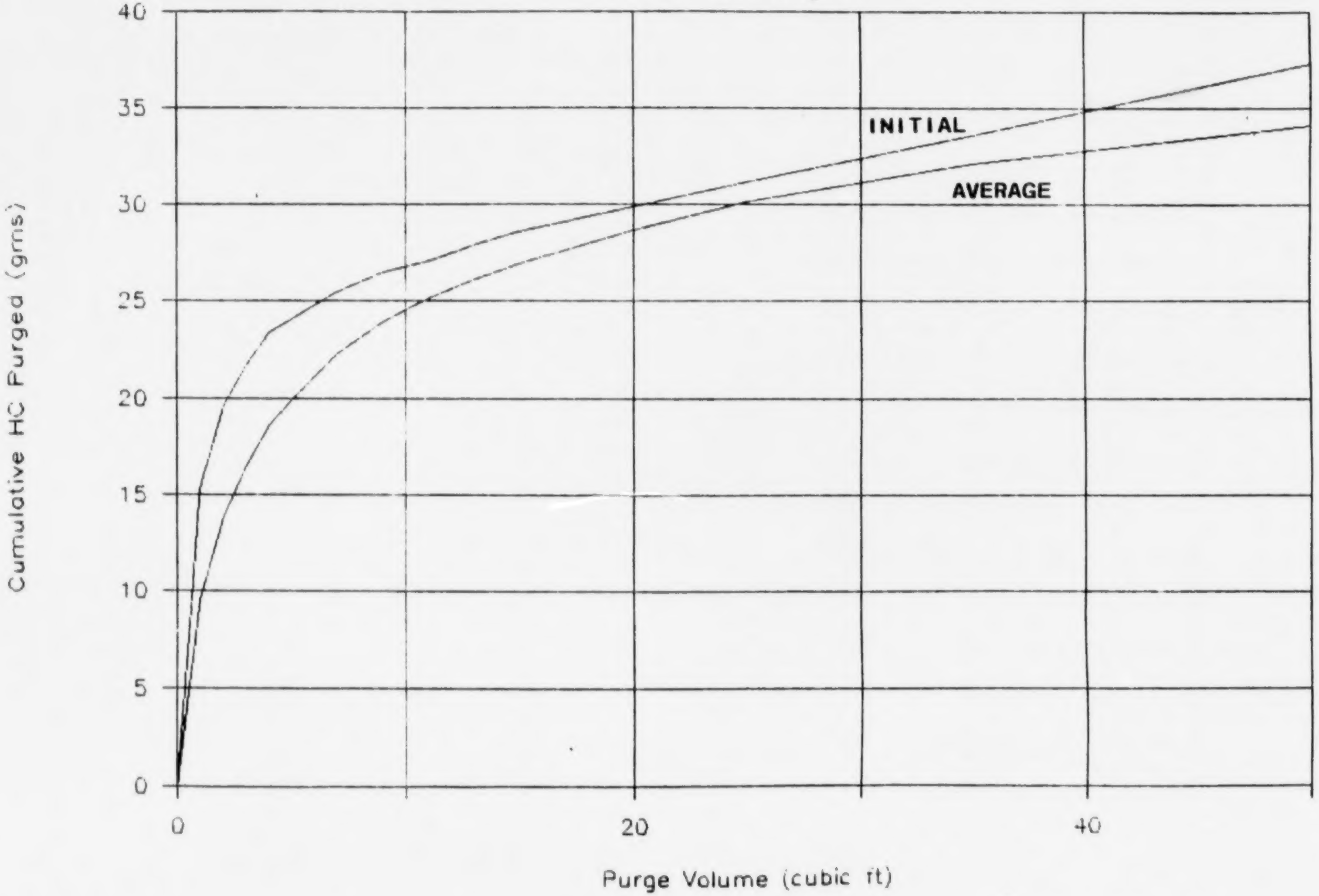


FIGURE A-3

INITIAL CURVE vs. AVERAGE CURVE

GM Durability



load/purge cycles are increasing the canister "heel." Therefore, the difference in the results on the Ford and Chrysler canisters versus the General Motors canister could have been due to the condition of the canister prior to testing. The results suggest that the General Motors canister was fairly well purged and the Ford and Chrysler canisters had more of a residual load. This was exactly the case. Each of these durability canisters (Ford, Chrysler, G.M.) was taken off of a vehicle that had completed its durability testing months earlier. As can be seen in Table A1, the Ford and GM vehicles were stored outdoors between completion of durability testing and the time of canister removal. (Though no information was available, it is safe to assume that the Chrysler vehicle was treated similarly). During that time the canisters were subjected to multiple diurnals and could be expected to have been thoroughly saturated. The difference between the Ford and the General Motors canisters is that General Motors attempted to "stabilize" the canister prior to delivering it to EPA. In this case, stabilization was achieved by driving the vehicle for four hours of AMA mileage accumulation with the evap canister onboard. This type of operation probably purged the canister quite thoroughly, and led to the difference between the plots of the initial tests on these canisters.

It should be pointed out here that the Nissan canister was also subjected to multiple diurnal loadings before delivery to EPA. There was, however, no significant difference between the plot of the initial canister tests and later tests.

B. Canister Aging

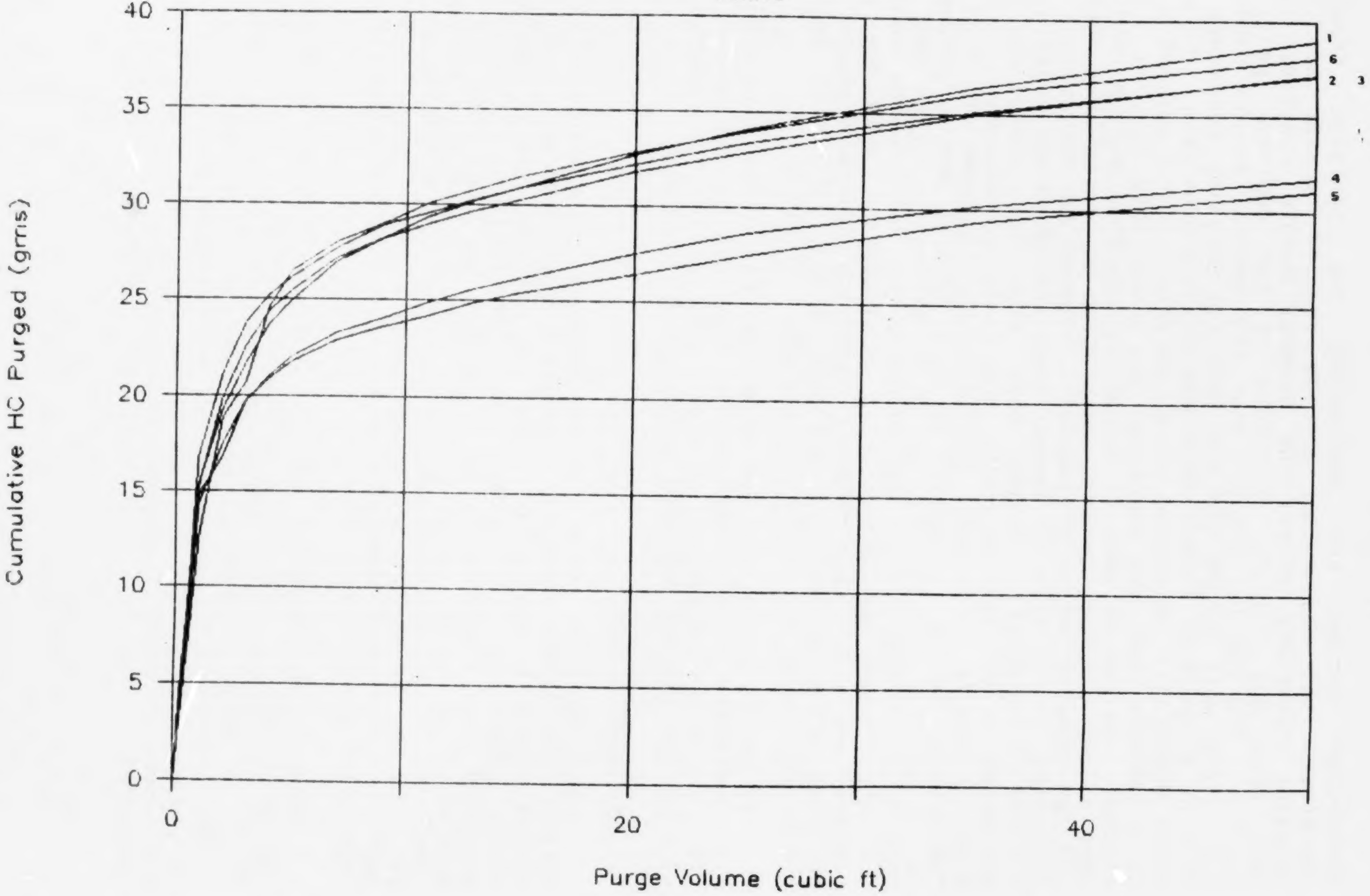
Canister aging refers to the process by which an activated carbon bed loses working capacity with repeated load/purge cycles until a stabilized level is reached. On a molecular level, aging is the process by which certain molecules are adsorbed onto the carbon bed in such a way that they are very difficult to remove. Although it might be possible to remove them with an extensive amount of purging, the effective working capacity of the carbon bed under normal, in-use purge modes is reduced. The aged condition appears to develop gradually over repetitive load/purge cycles.

One of the secondary goals of this program was to evaluate the magnitude of the aging effect. Because of the extensive amount of testing that would be required, it was outside the scope of this project to age a new canister from its virgin state to its stabilized level. It is unlikely that aging could be observed after the limited number of cycles possible during this test program. Figure A4 shows the first six tests performed on the new Ford canister. Although the first five

FIGURE A-4

FORD DURABILITY

AGING



tests tend to show a decrease in capacity with time, the sixth test shows the second highest working capacity in the group. This suggests that the difference between tests is being masked by test-to-test variability and no trend in working capacity can be established from this data.

Because of the time involved in aging a virgin canister, an alternative method of evaluating the effect of canister aging was needed. One logical approach was to perform a series of tests on a new canister (as outlined above) and to compare the results of these tests with the results of a series of tests done on an aged canister of identical design. Figure A5 shows four plots. The two upper curves were generated from the results of the tests on the new canister. The top curve is the purge record from the initial test on the virgin canister. The next curve is an average of the six plots shown previously in Figure A4. The lower two curves in Figure A5 were generated from the results of the tests on the Ford durability canister. The lowest shows the results of the first test performed on the durability canister after it was received by EPA and the final plot (labeled "durability average") shows the average of all the tests performed on the durability canister.

Figure A5 illustrates a few significant points. First, the original test on the virgin canister shows the highest working capacity of all the tests performed on the new and the durability canisters. Second, the average working capacity observed in the tests on the new canister is higher than the average working capacity of the durability canister. This suggests that some aging has taken place. Finally, the first test on the durability canister showed the lowest working capacity of all the tests, suggesting that the canister may have "aged" more than the average durability plot shows and that the repeated bench purge performed in this program has restored some capacity. Although the results of these tests are not a definitive measure of the effects of aging, the results do suggest that the durability canister has been aged to some extent. In this case, the durability canister appears to have lost about twenty percent of its original capacity.

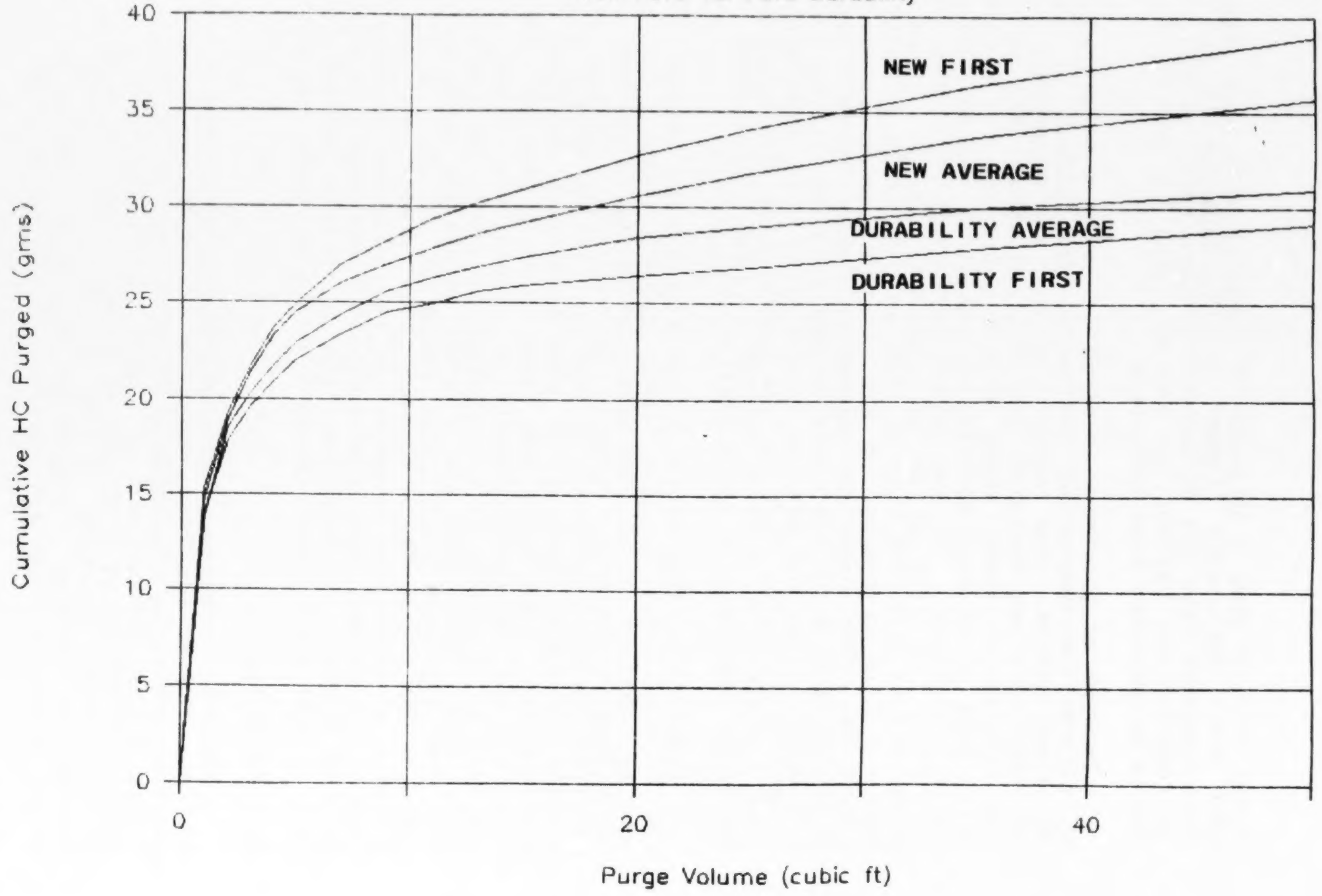
C. Purge Rate

Another secondary goal of this test program was to evaluate the effect that the rate of purge air flow has on canister stripping characteristics. If the rate of hydrocarbon stripping is independent of purge air flow rate then the cumulative amount of hydrocarbon purged from the canister would be a constant function of the volume of purge gas passing through the canister. Traces of cumulative hydrocarbon purged versus volume of purge air pulled through the canister would be

FIGURE A-5

CANISTER AGING

New Ford vs. Ford Durability



similar regardless of the purge air flowrate. However, because desorption is a mechanical process and the molecules in refueling vapors range widely in size, a dependence between purge air flow rate and the rate of hydrocarbon removal could be possible. In this program, an attempt was made to determine whether the amount of HC stripped from an activated carbon canister is a constant function of the volume of purge gas pulled over the bed, independent of purge air flowrate.

The effect of purge air flow rate on hydrocarbon stripping was investigated by performing three sets of purge tests on the Ford durability canister. Each set of tests was performed under identical conditions of purge, except that the purge air flowrate was different for each set of tests. The flowrates chosen were nominally 1/2, 1, and 2 cfm. Although these values may be somewhat high for current evaporative emission control system purge flowrates, it seems that flowrates of this magnitude may be necessary for some evap/refueling control systems.

As noted in the discussion of the canister weighing procedures, the results of this series of tests had to be corrected to account for time spent weighing the canister. For each test, it was assumed that the canister was purged for 55 seconds, and then the canister was disconnected and weighed. The weighing procedure was estimated to take approximately ten seconds. Therefore, ten seconds were substracted from the cumulative total for each canister weighing. Table A3 shows the corrected results of the tests used in the evaluation of the effect of purge rate on hydrocarbon stripping (tests E1 - E6). Each column represents the average of the two tests done at the purge rate shown at the top of the column.

The results of the tests designed to evaluate the effects of purge rate are plotted in Figure A6. Each curve represents the average of the tests done at one flowrate as marked on the figure. If the rate of hydrocarbon desorption were proportional to purge air flow rate, one would expect to see a pattern in the purge curves in Figure A6. Specifically, one would expect to see a steeper purge curve, and possibly a greater working capacity in the tests performed at the highest flowrate. An examination of Figure A6 shows that no such pattern is apparent. The curve generated from results of the tests performed using the lowest flowrate falls between the curves of the tests done using the higher flowrates. In addition, all of the tests are very similar and the differences between them are certainly within the range of test to test variability. Therefore, within the range of purge rates examined here, the amount of hydrocarbon stripped from the carbon bed is a function of the volume of purge air pulled over the carbon bed and is basically independent of purge air flowrate. What will happen at higher purge rates is unclear.

TABLE A3

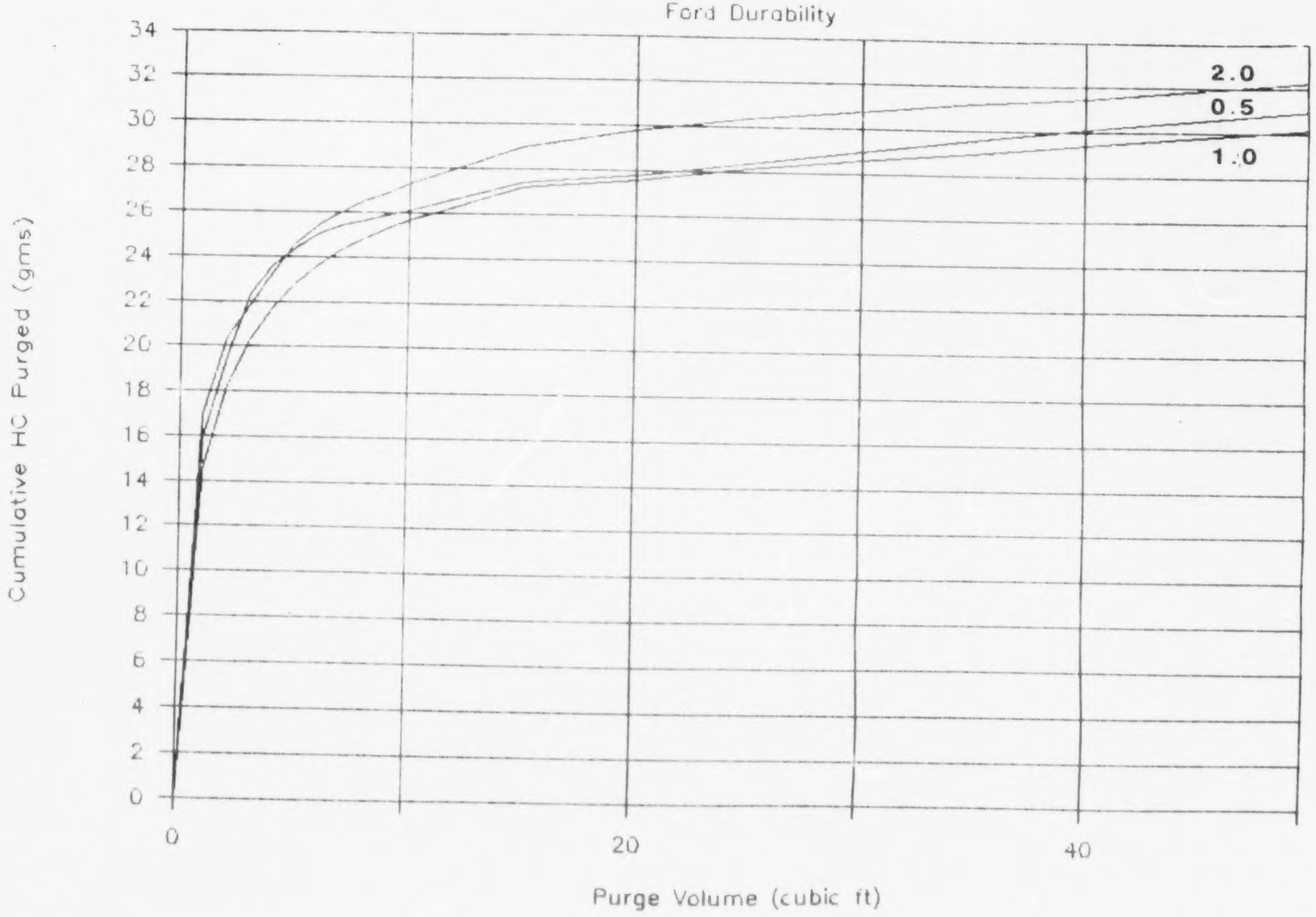
CORRECTED AVERAGE PURGE HISTORIES
FORD DURABILITY CANISTER

Volume of Purge Air (ft^3)	Purge Air Flow Rate		
	1.0	0.5	2.0
0	0	0	0
1	14.5	15.9	17.0
2	18.2	19.5	20.4
3	20.3	22.2	21.8
4	21.7	23.6	23.3
5	22.8	24.2	24.6
6	23.6	25.0	25.4
7	24.3	25.4	26.0
8	24.8	25.6	26.5
9	25.3	25.9	26.9
10	25.7	26.1	27.3
15	27.2	27.4	29.0
20	27.6	27.8	29.8
25	28.2	28.4	30.4
30	28.6	29.0	30.8
35	29.0	29.6	31.2
40	29.4	30.1	31.5
50	30.2	31.0	32.3

FIGURE A-6

EFFECT OF PURGE RATE

Ford Durability



D. Temperature of Purge

Canister temperature can effect both the loading and stripping of carbon beds. Increased temperature is equivalent to an increase in the kinetic energy of the molecules in the gas. An increase in the kinetic energy of air and hydrocarbons associated with a temperature increase in an activated carbon bed should cause a decrease in the amount of hydrocarbon adsorbed but should also aid the desorption process. This test program was focused on the process of purging hydrocarbons from a carbon bed, and therefore the temperature/loading interactions are not addressed. The effect of canister temperature on purge was tangentially investigated, however.

Fourteen tests were performed on the new Ford canister. In the first six tests, both the canister ambient and purge air temperatures were maintained at 95°F. In the thirteenth and fourteenth tests, the canister ambient and purge air temperature were held at 75°. Figure A7 shows two plots; one representing the average of the results of the tests in which canisters were purged at 95°, the other representing the tests using a 75° purge.

From the graph it appears that temperature has a distinct effect on purge. There are circumstances of the testing, however, which suggest that the results may be confounded. As mentioned above, the tests in which the canister was purged at 95° were the first six tests done on the new canister. The tests in which the canister was purged at 75° were the 13th and 14th tests performed on that canister. Although it is expected that extensive aging would not be observed after a limited number of cycles, any aging effects would bias the results of these tests toward the pattern observed in Figure A7. Although there is a possibility that the results of these tests may be somewhat confounded by aging effects, it appears that the increased purge temperature did have some effect on the amount of hydrocarbon that was stripped from the canister by a given volume of purge air.

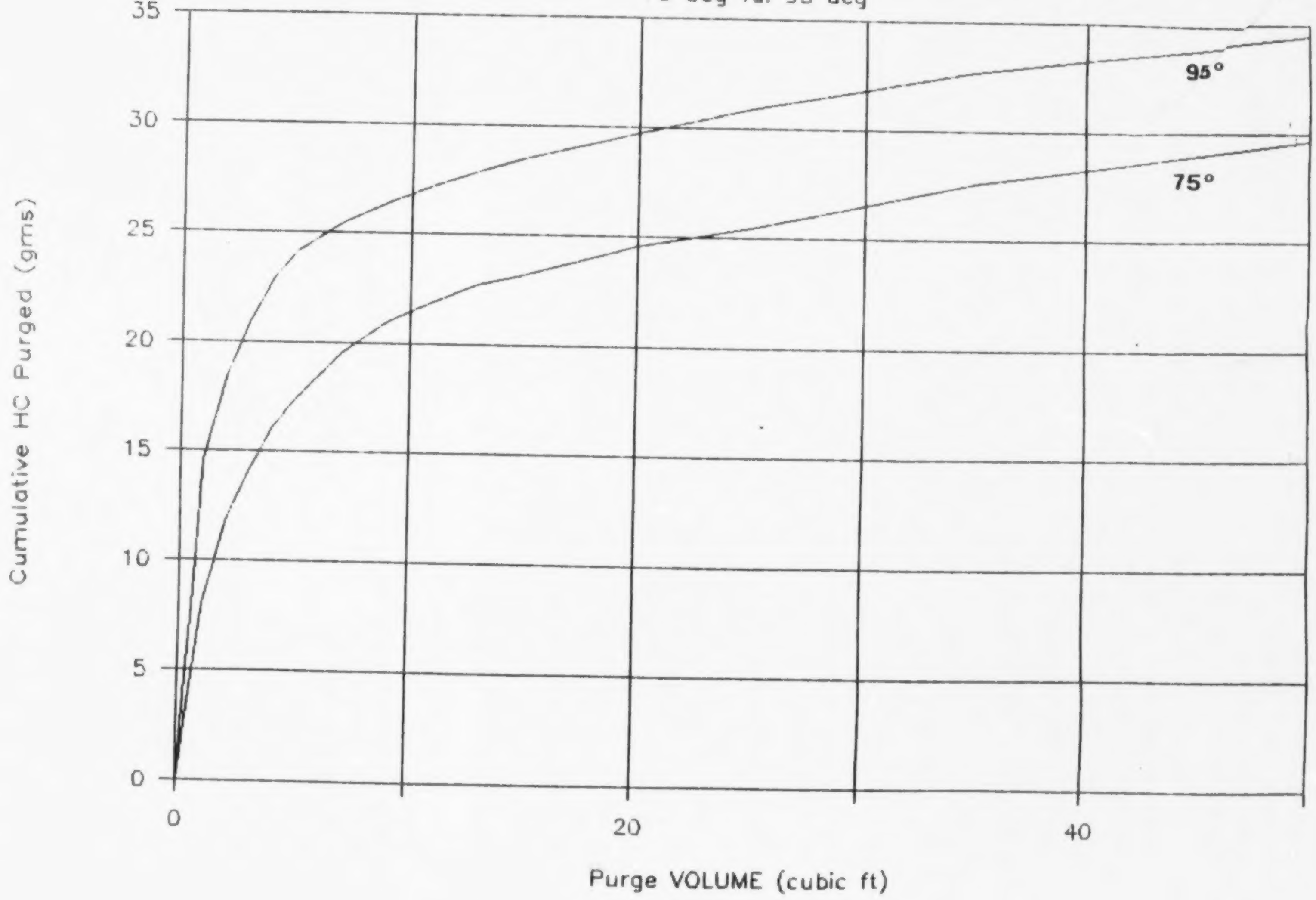
E. Representative Curves

As was stated previously, the main goal of this test program was to evaluate the purge response characteristics of several activated carbon canisters when loaded with refueling vapors. This was done by loading each canister to or near the breakthrough point with refueling vapors, and then pulling hydrocarbon-poor air over the activated carbon bed and monitoring the canister mass change as a function of purge air flow. The purge air flow rate and temperature of purge were generally held at 1.0 cfm and 95°F, respectively, during the

FIGURE A-7

EFFECTS OF TEMPERATURE

75 deg vs. 95 deg



canister purge sequences.* Average curves were then generated for each canister. The average curves for the four evap canisters from durability vehicles are shown in Figure A8. Figure A9 shows the curve for the EPA canister, which was designed and built as a refueling canister and has a working capacity much larger than the evaporative canister capacities.

The plots of the average curves are valuable in that some understanding of the differences in the purge response of the various canisters (as measured by the differences in the shapes of the various curves) can be gained. It is difficult to use the curves to fully evaluate the performance of the various canisters however, because some of the differences are simply due to the fact that the canisters are not all of one size. Although there are several variables other than size that may affect the performance of the canisters (carbon type, shape, and interior configuration, to mention a few), this program was not designed to investigate the effects of the differences in canister designs. The differences in the curves due only to differences in size can be effectively eliminated, however.

The differences in canister sizes were eliminated by normalizing the average curves presented in Figures A8 and A9 by canister volume. In scaling the canister curves, the characteristic shape of each curve was preserved, but the purge curves were scaled to represent the results expected for a one liter canister. The normalization was done by dividing the X and Y components of the points on the average curve by the canister volume (in liters). The use of this scaling technique implicitly assumes that a small canister designed exactly like a large canister (in terms of length to diameter ratio, interior configurations, carbon base, etc.) would demonstrate stripping characteristics (for equivalent amounts of activated carbon) identical to those of the large canister. For example, a half-sized canister purged half as much would release half the hydrocarbons that a full sized canister would.

The volume-normalized purge curves are shown in Figure A10. The curves are labeled with the source (or supplier) of the canister as well as with the base material used in the production of the activated carbon. Several features of Figure A10 are worthy of discussion. The first thing that is noticeable in Figure A10 is that the curve generated from the

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* Three purge rates were used in the tests on the Ford durability canister, but as discussed in the section on the effects of purge rate, this had little impact on the results.

FIGURE A-8

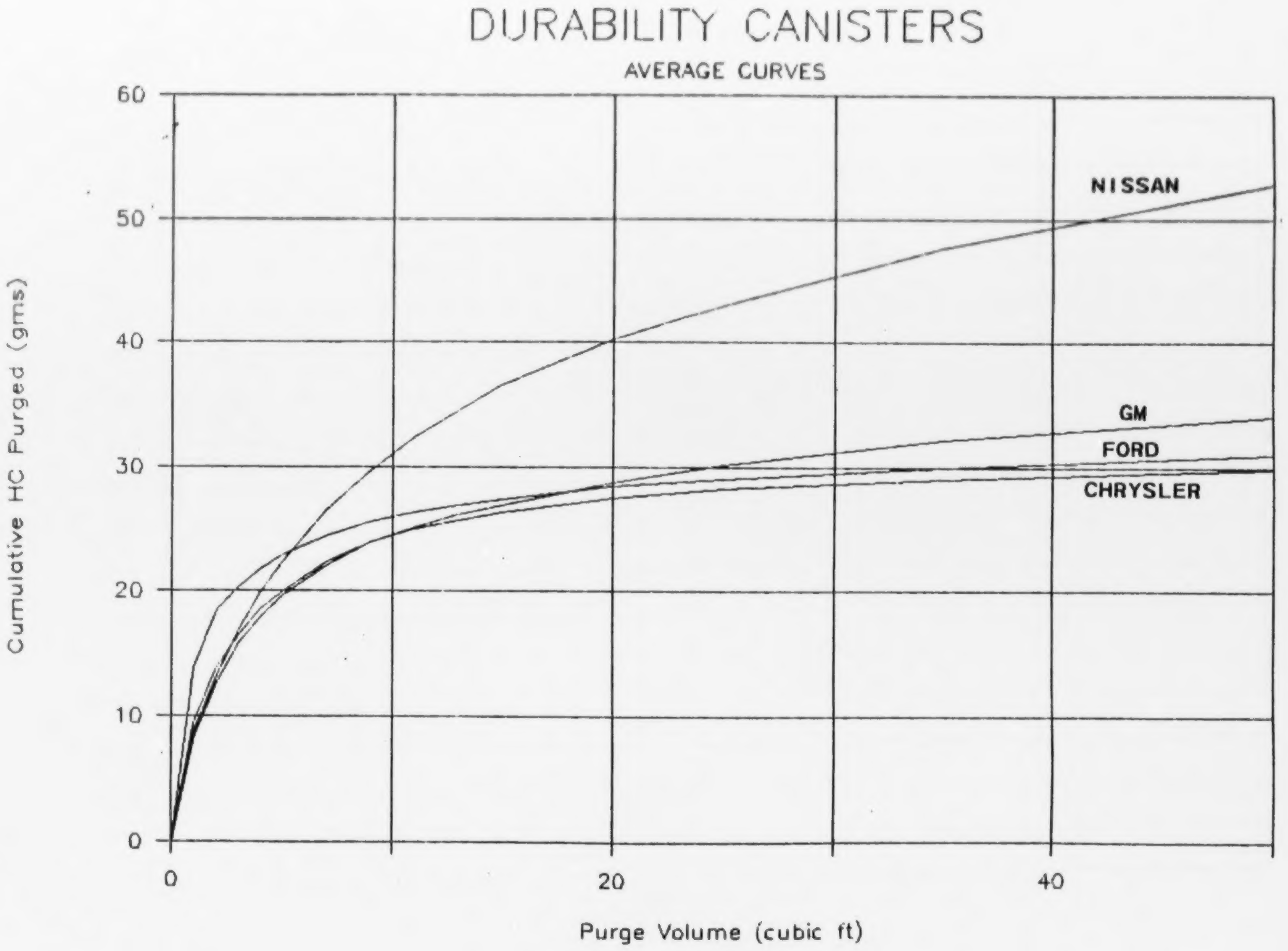
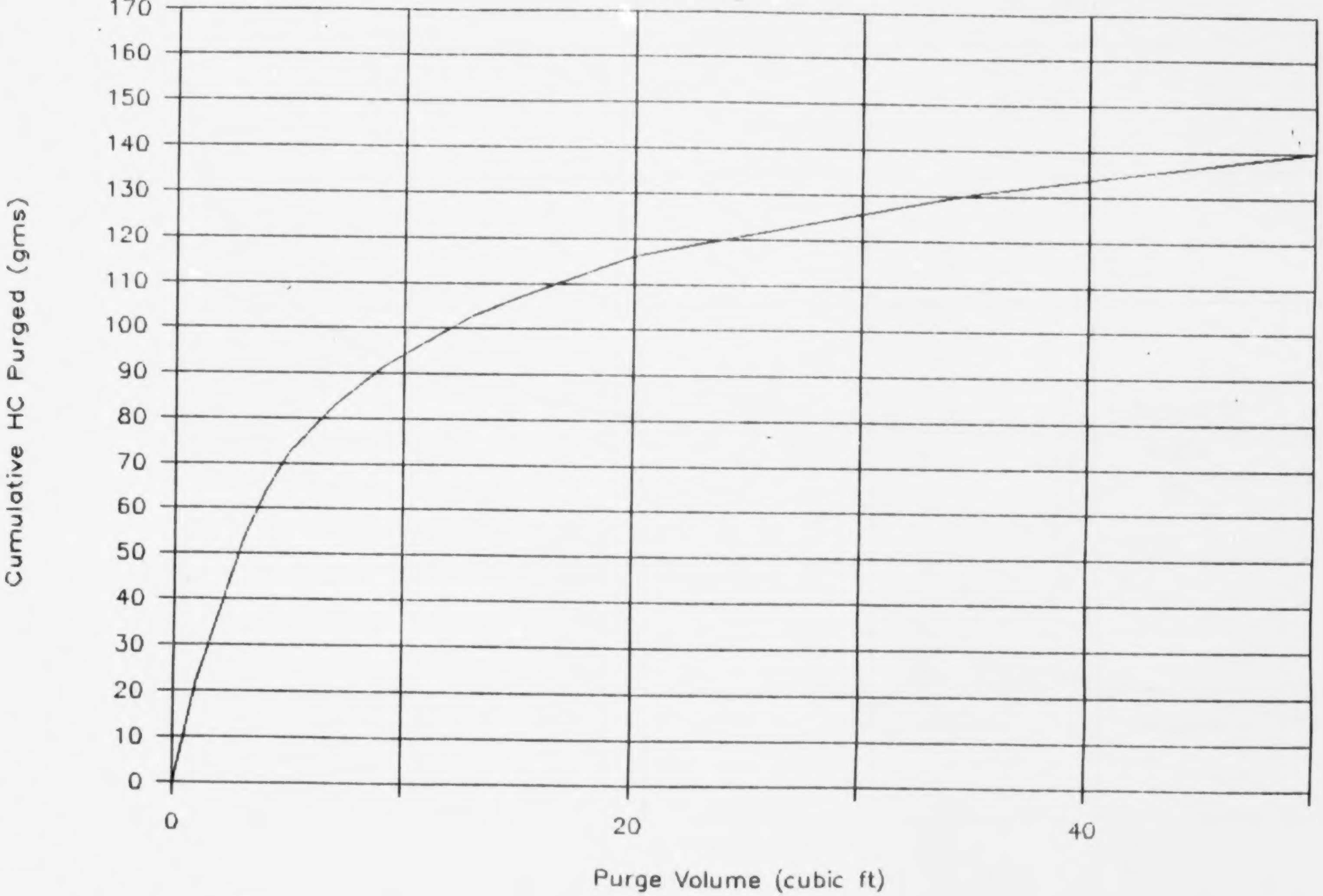

DURABILITY CANISTERS
AVERAGE CURVES
NISSAN
GM
FORD
CHRYSLER
Cumulative HC Purged (gms)
60
50
40
30
20
10
0
0
20
40
Purge Volume (cubic ft)

FIGURE A-9



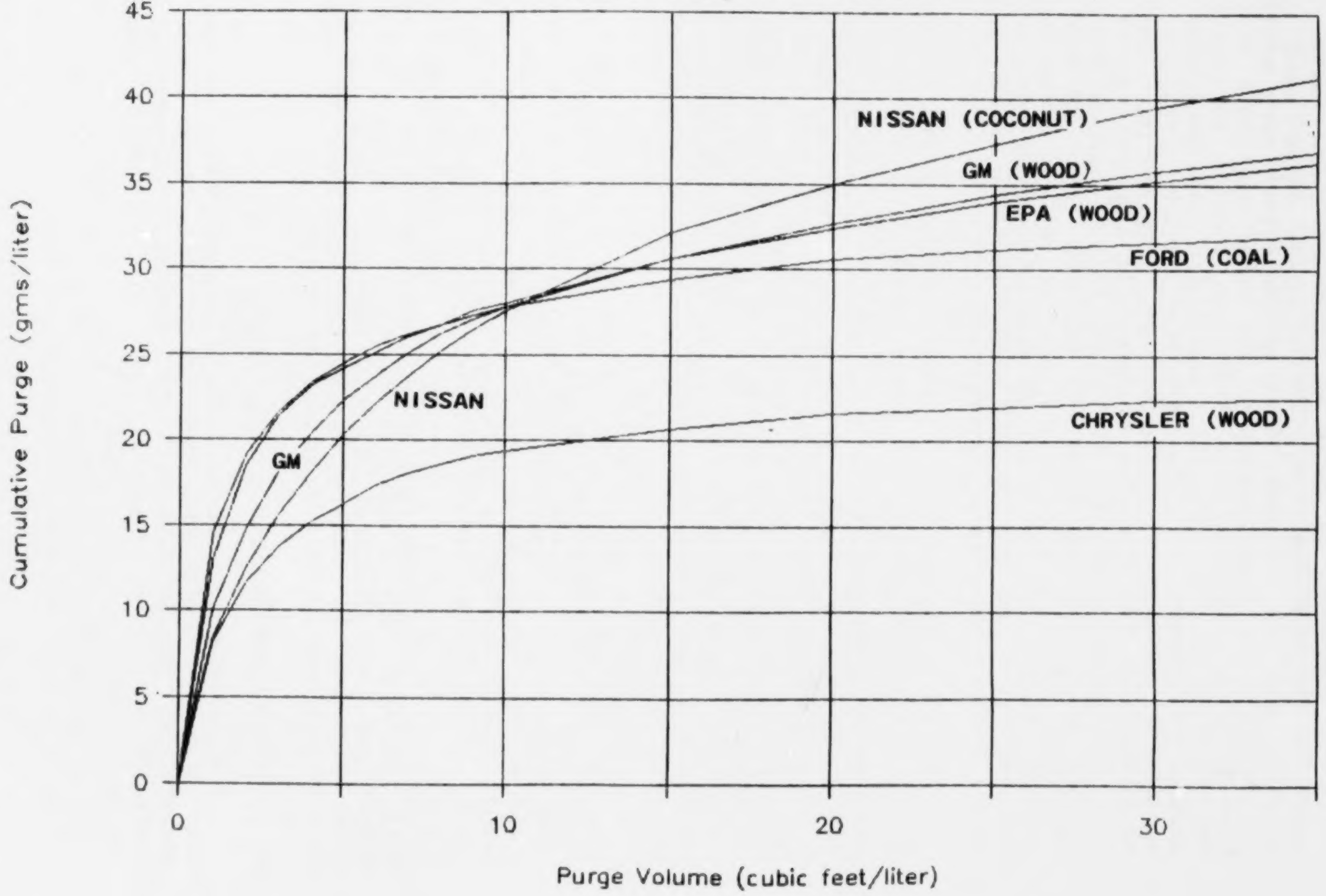
EPA CANISTER

Average Curve

FIGURE A-10

REPRESENTATIVE CURVES

Normalized by Canister Volume



results of the tests on the Chrysler canister is isolated from the rest of the curves. An examination of the information on canisters presented in Table A1 reveals nothing extraordinary about the Chrysler canister. The activated carbon used in this canister and the canister construction appear very similar to the material and construction of the other canisters tested in this program. Chrysler was unable to provide information on the history of the canister, and there may have been some unusual treatment of the canister which lead to these unexpected results. Although no explanation for the performance of the Chrysler canister is apparent, it is clear that the results of the tests on this canister fall well outside of the range predicted by the tests of the other canisters. Because the results of the tests on the Chrysler canister cannot be explained by the information available to EPA, the curve for the Chrysler canister will not be included in any further analysis of the results.

The main feature of interest in Figure A10 is that it shows the differences in the purge response characteristics of similarly sized canisters of several designs. The Nissan canister apparently releases hydrocarbons relatively grudgingly during the initial stages of purge, but shows a less drastic decay of hydrocarbon stripping as the purge process continues. The Ford canister lies at the opposite end of the purge response spectrum. This canister type apparently gives little resistance to hydrocarbon removal during the initial stages of purge, but the hydrocarbon stripping rate drops quite rapidly thereafter. The other two curves (the G. M. and EPA curves) fall within these extremes.

Also shown in Figure A10 is the type of carbon used in each of the canisters tested. Looking at the right side of Figure A10 it appears there might be a distinct purge curve for each carbon type. Upon examining the left side of the figure, however, it can be seen that the Ford (coal base) and EPA (wood) curves are almost identical through the early stages of purge. The Nissan curve is distinct throughout its purge history, however, and there may be some differences in the fundamental absorption/desorption characteristics of coconut based carbons. The comparison of purge curves by carbon type should not be emphasized, however, because there are several other variables in canister design that could not be separated from carbon type by this experimental design.

F. Canister Temperature During Purge

The canister listed in Table A1 under "EPA" was designed and built for refueling emission control tests. When this canister was loaded with activated carbon, a thermocouple was installed in the canister so that internal canister temperatures could be measured as needed. The thermocouple was used to monitor internal canister temperature during two of the purge sequences done on the refueling canister.

The trace of canister temperature as a function of the volume of purge air pulled through the canister for one of these tests is shown in Figure A11. As can be seen from the trace, the desorption process absorbs heat. The temperature of the canister drops from its peak (measured at 135°F immediately after loading) down to its lowpoint (70°F, 6°F below the ambient) in under 10 minutes. The canister temperature then climbs back to the ambient in about ten minutes and remains near the ambient throughout the remainder of the purge.

This information is significant for two reasons. First, as hydrocarbon is stripped from the canister, the temperature of the canister falls rapidly. The decrease in temperature could tend to inhibit the removal of more hydrocarbons. Second, as noted above, the canister temperature can fall below the ambient during the purge and in certain situations the internal canister temperature could fall below the dewpoint resulting in condensation inside the canister. Although this situation would probably not arise with any regularity, condensation inside the canister could occasionally occur.

G. Conclusions

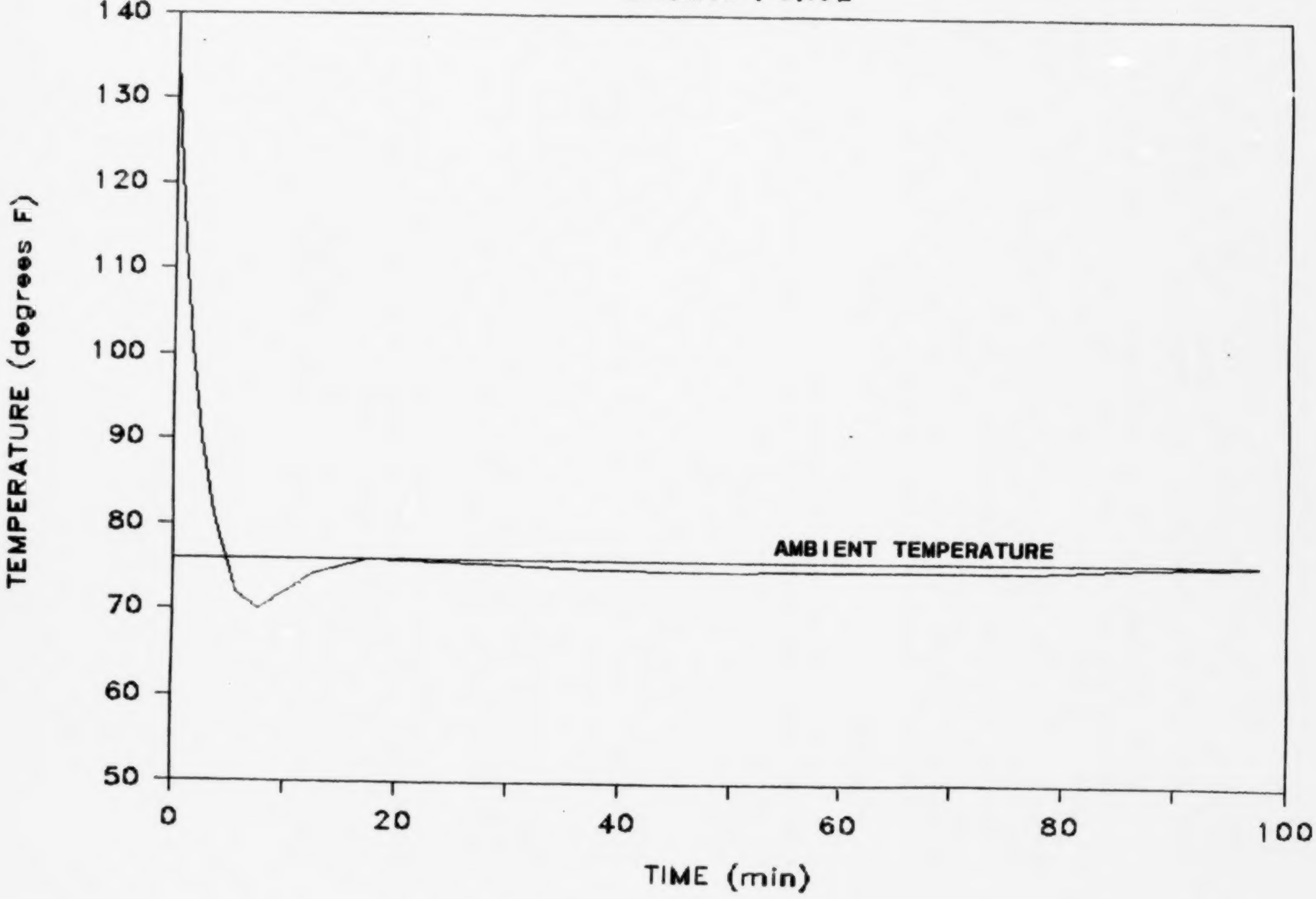
As stated in the introduction to this paper, this test program had one primary goal and several secondary goals. The primary goal of the program was to evaluate the purge response characteristics of several canisters of different designs. Part of this evaluation was the development of "purge curves" which could be used in the development of a procedure for evaluating the purge capability of onboard refueling emission control systems. The secondary goals of the program were to investigate the effects of aging, purge air flow rate and purge air temperature on hydrocarbon stripping characteristics. In the course of gathering data to address the topics mentioned above, information was also obtained on internal canister temperatures during the purge process. Although this test program had a limited scope several useful conclusions can still be drawn from the data.

The conclusions that can be drawn concerning the secondary goals of the program were stated as part of the analysis of results. The results of the tests to develop representative curves for the various canisters merit some further discussion, however. The remainder of this section describes the manner in which the representative curves can be

FIGURE A-11

CANISTER TEMPERATURES

DURING PURGE



used in the development of a refueling test procedure, and some recommendations for improvements in the experimental design used in this program.

A test procedure designed to evaluate the effectiveness of onboard control systems must test the ability of the system to provide capacity for the storage of refueling emissions. In the case of a system that uses activated carbon as the storage medium (which is expected to be the case), this involves stripping hydrocarbons from the activated carbon bed by pulling hydrocarbon poor air across it. A basic understanding of the relationship between hydrocarbon stripping and purge air flow is needed in order to develop a procedure which adequately tests the purge capability of the control system. The main purpose of this test program was to develop a series of purge curves which could be used to represent the range of purge response patterns that could be expected of onboard control system canisters.

The representative purge curves developed in this program are shown in Figure A10. These curves represent the expected performance of one liter canisters of the same design as those used in the test program. As discussed in the analysis of data, the curve for the Chrysler canister falls well outside of the range of curves generated from the data from the other canisters. Since there is no evidence to suggest that the Chrysler canister is radically different from the other canisters in terms of material or design, the curve generated for this canister is probably not representative of this canister's typical performance.

The remaining curves fall within a relatively narrow band in Figure A10. Although the curves are closely grouped spatially, there are significant functional differences across the curves in that range. The curve representing the performance of the Ford canister rises quite sharply and shows a relatively clear breakpoint early in the purge process after which the curve flattens out. The curve generated from tests on the Nissan canister is less steep in the initial stages of purge and tends to break over more gradually. The curves for the Ford and Nissan canisters are the most dissimilar of those in Figure A10 (excluding the Chrysler curve). Because these curves are the most dissimilar, they can be used to represent the range of response patterns expected from activated carbon canisters. Therefore, these two curves were used in the analysis performed in the development of the refueling test procedure.

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